THE AMERICAN MINERALOGIST
JOURNAL OF THE MINERALOGICAL SOCIETY OF AMERICA

Vol. 21 DECEMBER, 1936 No. 12, Part 1

THE FUSION RELATIONS OF IRON-ORTHOCLASE

WITH A DISCUSSION OF THE EVIDENCE FOR THE EXISTENCE OF AN IRON-ORTHOCLASE MOLECULE IN FELDSPARS*

GEORGE T. FAUST

ABSTRACT

An examination of the equilibrium relations existing along the section $K_2O \cdot 6SiO_2$ (glass)†–Fe_2O_3 of the ternary system K_2O–Fe_2O_3–SiO_2 has shown that the compounds iron-orthoclase ($KFeSi_3O_8$) and iron-leucite ($KFeSi_2O_6$) exist, and that they can be prepared from dry melts. On heating, the iron-orthoclase dissociates into iron-leucite and a liquid, and the iron-leucite in turn dissociates into hematite and a liquid. Hematite is the stable phase at the liquidus 1265°C. The difficulty in the synthesis of iron-orthoclase can be traced, in part, to these complex incongruent melting relations. Powder x-ray diffraction patterns indicate the similarity of the two potash-iron-silicates with the corresponding aluminum compounds. The question of the ferric feldspars and the entry of the iron-orthoclase molecule into the feldspars proper has been critically reviewed.

TABLE OF CONTENTS

I. Introduction
II. Historical
III. Methods of studying phasal relations in silicate melts
IV. Preparation of the mixtures
    SiO_2 component
    K_2O component
    Fe_2O_3 component
V. The furnaces and measurement of temperatures
    Crystallizing furnace
    Quenching furnace
    Accuracy of temperature control
    Thermometric measurements
VI. Refractive indices and the ferrous oxide content of the glasses

---

* A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the University of Michigan.

† This designation does not signify a compound of K_2O and SiO_2 in the ratio of 1:6, but is a convenient method of expressing the molecular composition of the mixture.

VII. Quenching experiments
    Field of hematite
    Field of iron-orthoclase
    Field of iron-leucite
    Field of the silica minerals

VIII. Properties of the crystalline phases
    Iron-orthoclase
    Iron-leucite
    Hematite
    Silica minerals

IX. Discussion of the evidence for the existence of an iron-orthoclase molecule in feldspars
    Chemical and physical data
    Occurrence of ferriferous feldspars
        The occurrence of a ferriferous-orthoclase
        The occurrence of other iron-bearing feldspars
    Evidence from synthetic studies
        Experiments of Hautefeuille and Perrey
        Evidence from the present studies
    Interpretations

X. Acknowledgments

I. INTRODUCTION

The ternary system $K_2O–Fe_2O_3–SiO_2$ is seemingly unimportant in petrology, owing to the lack of any indication of its compounds occurring alone in nature. It is, nevertheless, of interest in the explanation of their significant absence in igneous rocks. In this paper the relations obtaining along the $K_2O \cdot 6SiO_2$(glass)–Fe_2O_3 section will be considered in so far as they permit interpretation. Experimental study of the system $K_2O \cdot 4SiO_2–Fe_2O_3–SiO_2$ is in progress.

This investigation was undertaken to determine the existence or nonexistence of certain compounds thought to form in the ternary system here considered. The compound $K_2O \cdot Fe_2O_3 \cdot 6SiO_2$, which for the purpose of mineralogical analogy may be termed iron-orthoclase, has been prepared by French mineralogical chemists. They, however, prepared it by using catalytic or mineralizing substances and not from the simple ternary components.

Although up to the present no conclusive evidence of the existence of iron-orthoclase as a distinct mineral species has been reported, its manifestation in nature may be masked by isomorphism with the analogous aluminum compound orthoclase, $K_2O \cdot Al_2O_3 \cdot 6SiO_2$, and some credence is given to this belief through the discovery of a yellow iron-bearing orthoclase from the area near Fianarantsoa, Madagascar.

For this and other reasons it was considered very desirable to investigate and compare the phasal relations obtaining in this system with those in the analogous system Na_2O–Fe_2O_3–SiO_2, and these results will be published later when the work is completed.

In addition, when the principal portion of the system is worked out, the phasal relations as deduced from the liquidus curves may be of use in helping to determine the course of crystallization of the residual liquids rich in iron, which are believed to exist in the later stages of the cooling of some rock magmas.

Moreover, the results of the present study may also be of some value to the glass industry, for the section studied contains the $K_2O:SiO_2$ ratio present in many hard glasses; and the effects of the oxides of iron on the refractive index and the liquidus, will be more accurately known.

II. HISTORICAL

Various investigators in mineral synthesis have attempted the preparation of certain compounds in this system. Thus, Hautefeuille[1] as early as 1880 prepared what he terms "leucite ferrique," $K_2O \cdot Fe_2O_3 \cdot 4SiO_2$, by pouring into molten potassium metavanadate, stoichiometric proportions of potassium nitrate, silica, and ferric oxide, and obtained a product consisting of yellow-green, icositetrahedral crystals showing the characteristic polysynthetic twinning of the mineral leucite. In 1888 Hautefeuille and Perrey[2] succeeded in isolating what they called "orthoclase ferrique," $K_2O \cdot Fe_2O_3 \cdot 6SiO_2$, as amber-yellow crystals possessing similar crystallographic and optical properties, including the characteristic Karlsbad, Manebach and Baveno twins, of the mineral orthoclase. Niggli[3] obtained by the methods of hydrothermal synthesis "Kaliägirin," crystallizing as long slender prisms or clusters, and possessing a light yellow-green color. This compound possesses the same chemical formula as the "leucite ferrique" of Hautefeuille; and, Niggli attempts to explain this in the following manner:

> Through the preparation of the potassium-aegerite there is now produced a connection between the leucite form and the amphibole-pyroxene form of the silicate $R'R'''Si_2O_6$. The compound $KFeSi_2O_6$ crystallizes out of vanadate-bearing melts as iron-leucite, which under ordinary hydrothermal conditions forms as potassium-aegerite.

In this connection it would be well to recall the actual observations of Larsen and Hunt[4] who investigated two vanadiferous soda-aegerites from Libby, Montana, and gave analyses from which the following data in Table 1 are taken:

---

[1] Hautefeuille, P., *Compt. rendus*, vol. **90**, pp. 378–380, 1880.

[2] Hautefeuille, P., and Perrey, A., *Compt. rendus*, vol. **107**, pp. 1150–1152, 1888

[3] Niggli, P., *Zeit. anorg. Chem.*, vol. **84**, pp. 31–55, 1914.

[4] Larsen, E. S., and Hunt, W. F., *Am. Jour. Sci.*, vol. **36**, pp. 289–296, 1913.

TABLE 1

	Vanadiferous-Aegerite	Vanadiferous-Aegerite-Augite
Na_2O	10.46%	6.26%
K_2O	0.22	0.26
V_2O_3	3.98	2.86

They state further:

> These two pyroxenes occur together in veins that were probably formed under deep-seated conditions and at a high temperature. Indeed they have some resemblance to pegmatites.

Thus the discovery of a vanadiferous soda-aegerite does not substantiate the generalization regarding the phase of $R'R'''Si_2O_6$ to be expected according to Niggli's interpretation. Furthermore, iron-leucite was prepared from dry melts in this present study.

In addition, Duboin[5] using molten potassium fluoride as a bath has also prepared an iron-leucite of the composition $K_2O \cdot Fe_2O_3 \cdot 4SiO_2$.

III. THE METHOD OF STUDYING PHASAL RELATIONS IN SILICATE MELTS

Silicate melts possess great viscosity and hence offer resistance to the attempt of molecules, or atomic groups, to arrange themselves in an orderly fashion to form crystals.

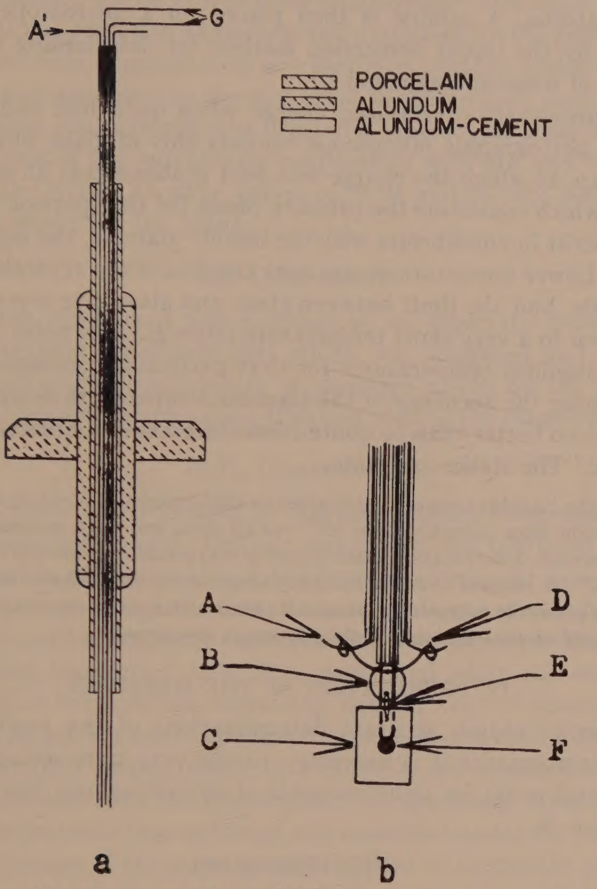
Since the silicate melts, in general, exhibit heating curves which do not give evidence of a sharp break, but rather show a melting interval, the determination of the liquidus must be investigated by some other method. The method used to investigate silicates, which exhibit sluggish tendencies to crystallize, is known as the "quenching-method" and was originally described by Shepherd, Rankin and Wright[6] in 1909.

In this method a small quantity of the charge is placed in a tiny platinum envelope which is suspended in the furnace and left there for a period judged to be sufficient to ensure the attainment of equilibrium conditions. After measuring the temperature at equilibrium, the charge is immediately removed from the furnace by an electrical device[6] which fuses a small platinum wire suspending the charge and causes the envelope with its contents to be dropped out of the furnace into a mercury well where it is quenched to room temperature. See Fig. 1.

By this method of quenching it is possible to bring the charge down to room temperature rapidly enough so that the phase or phases which are present in the furnace at the temperature of equilibrium are preserved.

[5] Duboin, A., *Compt. rendus*, vol. **185**, pp. 416–417, 1927.

[6] Shepherd, E. S., Rankin, G. A., and Wright, F. E., *Am. Jour. Sci.*, vol. **28**, p. 293, 1909.



FIGS. 1 (a and b). The "quenching rig." (Fig. 1b represents a more highly magnified portion of the lower part of the apparatus.)

The wires making up the thermoelement and heavy platinum lead wires are encased in porcelain capillary tubes.

AA′ = Heavy platinum lead wires.
B = Refractory (porcelain) ring.
C = Envelope made of platinum foil.
D = Fine platinum wire connecting the refractory ring to the heavy platinum lead wires AA′. Note:—it is this wire that is fused when the charge is dropped out of the furnace.
E = Fine platinum wire connecting the platinum envelope to the refractory ring.
F = The tip of the thermocouple.
G = The thermocouple wires before entering the capillary tubes.

The charge is removed from the platinum envelope by placing it in an agate mortar and crushing it with the pestle to loosen the charge from the foil. A brass collar may be used to surround the charge to prevent loss of material. A sample is then placed on a microscope slide and examined by the liquid immersion method for determining the optical constants of mineral fragments.

If the previously crystallized charge when quenched and examined under the petrographic microscope consists only of glass, obviously the temperature at which the charge was held is above that at which those crystals (which constitute the primary phase for that portion of the system) can exist in equilibrium with the liquid—namely, the liquidus temperature. Lower temperatures are next tried until the crystals are found to be stable, and the limit between glass, and glass plus crystals, is narrowed down to a very short temperature interval. This point then represents the liquidus temperatures for that particular composition.

Concerning the accuracy of the liquidus temperature determinations, one can do no better than to quote from the excellent, critical discussion of Kracek.[7] The italics are mine.

> Thus, if the liquidus temperature is given as 764°, interval +3 −2, it is meant that the preparation when quenched from 767° was all glass, and when quenched from 762° contained crystals. *Since the thermostatic control of the furnace is accurate to 0.5°, the limits 767° and 762° are intended to denote that these temperatures are known to the nearest 0.5° of the values given; the interval then denotes the limit within which the transformation was determined, and not the uncertainty of the temperature measurement.*

IV. PREPARATION OF THE MIXTURES

In order to obtain accurate determinations of the position of the liquidus temperature it is necessary to use very pure materials in the experimental work, for small amounts of impurities may have a decided effect upon it.

SiO_2 Component

This was prepared from Sylvania sandstone, which is weakly bound with calcite as cementing material. A preliminary examination made in 1930 by Professor W. F. Hunt[8] showed the presence of small quantities of celestite, garnet, pyrite, tourmaline, magnetite, and zircon as the heavy residues. The sandstone was crushed, sieved, and the heavy minerals separated by means of bromoform. The sand was then boiled with dilute acids until the acid extractions no longer yielded a test for iron. The resulting material was then washed free of acid, dried, and heated in a platinum crucible to approximately 1450°C. for a period of ten to twelve hours. This heating inverts most of the quartz and owing to the consequent volume changes a white powder is produced which is very easy to crush. The break-down of the grains exposes the small cracks in which adsorbed oxides of iron cling tenaciously. After again crushing, the material was placed in a casserole and digested with the acid mixture; and the iron oxide, together with any platinum crystals which may have volatilized and deposited on the sand while in the furnace, were removed. After washing, the material was dried and stored over P_2O_5 in a desiccator. Analysis of two samples by evaporation with HF and H_2SO_4 and ignition with $(NH_4)_2CO_3$ gave values of 99.94 and 99.93% SiO_2, corrections being made for the blank.

---

[7] Kracek, F. C., *Jour. Phys. Chem.*, vol. **36**, pp. 2529–2542, 1932.

[8] Hunt, W. F., Oral communication.

K_2O COMPONENT

The potash component was supplied by an especially pure $KHCO_3$ analytical reagent (Mallinckrodt) which was analyzed and found to meet the minimum requirements of standard works on the purity of reagents.[9,10] Several samples upon titration yielded the theoretical factor.

Fe_2O_3 COMPONENT

The iron oxide was prepared by starting with an exceptionally pure ferric ammonium sulphate. The salt was placed in a platinum casserole and dissolved in distilled water; a few drops of nitric acid were added to ensure the ferric state of the iron, and ammonia gas was bubbled into the solution until a decidedly basic reaction was observed. The precipitate was then transferred to a filter paper and while still warm, was washed with a hot solution containing one per cent of ammonium nitrate, until no further tests for sulphate could be detected. This precipitate was carefully dried, placed in a crucible (porcelain) and heated, slowly at first and then the temperature was gradually raised to below 1000°C. The material thus obtained was examined under the microscope and also by means of the *x*-ray powder method to ensure the absence of magnetite.

To check the accuracy of the quantitative determinations, Dr. Kenneth B. Thomson,[11] Research Spectroscopist in the Department of Physics in the University of Michigan, very kindly investigated the purity of samples of the three components by an examination of their spectra of which he states:

> The quartz shows no strong lines other than those of silicon and two or three weak lines which are probably silicon lines but were not listed in the tables at hand.
>
> There is no evidence of any titanium in the ferric oxide preparation and only an exceedingly small amount of aluminum and silicon. The presence of the aluminum is however, not definitely established.

---

[9] *Chemical Reagents; Their Purity and Tests.* Merck & Co., 1914.

[10] Murray, B. L., *Tests for Reagent Chemicals*, 2nd Ed., New York, 1927.

[11] I desire at this time to thank Dr. Thomson for his willingness to analyze these preparations.

For the analysis of the $KHCO_3$, a solution (prepared) containing 3 grams of $KHCO_3$, 5 c.c. of HCl and distilled water to make up to 100 c.c. This solution was run against a blank containing 5 c.c. of HCl and 95 c.c. of water and a known solution containing 0.05% Na, and in addition 0.01% Mg, 0.01% Mn, 0.005% Cu, 0.05% Ca, 0.3% K, all present as chlorides. The sodium in the $KHCO_3$ *if any* is exceedingly small and judging by comparison with the standard solution containing 0.05% Na, the amount would be probably less than 0.01% of this value. Further, Mg, Ca, Fe, and Al lines were all absent.

The $K_2O \cdot 6SiO_2$ glass[12] was prepared by weighing directly into a platinum crucible the stoichiometric proportion of SiO_2 required by the molecular composition of the glass. The correct proportion of $KHCO_3$ necessary to yield the theoretical quantity of K_2O required was weighed out on a watch glass and added to the silica. The two were carefully mixed on a piece of glazed paper and returned to the crucible, which was then placed over a bunsen flame and heated *gently* for two hours. The crucible containing the charge was removed and placed in a Hoskins furnace at approximately 800° to 900°C. and left for twelve hours, after which it was transferred to the crystallizing furnace and held at 1100°C. for a short period of time. The temperature of the crystallizing furnace was then raised to 1400°C. and the charge kept in it for five hours. The charge was finally removed from the furnace, cooled quickly, and placed in a desiccator over P_2O_5.

This method of heating was followed for several reasons. In the first place, CO_2 is expelled from the melt and in order to minimize losses of K_2O and silica from the melt due to mechanical causes it is necessary to reduce frothing. Secondly, Kracek[7] has shown that glasses free of CO_2 lose very little K_2O by direct volatilization, even at high temperatures; thus, the careful heating tends to expel the CO_2 with the minimum loss of K_2O. Even with all these precautions, some K_2O is unavoidably lost. In order to compensate for this loss, the cooled crucible of $K_2O \cdot 6SiO_2$ glass was weighed and the loss in weight was taken as due entirely to the volatilization of K_2O; for Sosman[13] states that:

> The direct volatilization of silica at temperatures below 1600°C. has not been proved.

A quantity of potassium bicarbonate sufficient to supply the amount of K_2O lost was therefore added to the powdered glass and the mass re-fused three times with fine crushing between fusions, until homogeneity was obtained.

The glasses on the section were made by adding weighed quantities of Fe_2O_3, corresponding to definite compositions, to the homogeneous $K_2O \cdot 6SiO_2$ glass, mixing thoroughly and heating. The resulting glass was crushed and reheated until optical examination showed the absence of undissolved iron oxide and the new glasses appeared homogeneous. This usually requires as many as six fusions with intervening grindings. The glasses thus obtained were placed in the crystallizing furnace.

---

[12] This designation does not signify a compound of K_2O and SiO_2 in the ratio of 1:6, but is a convenient method of expressing the molecular composition of the mixture.

[13] Sosman, R. B., *The Properties of Silica*, New York, p. 109, 1927.

V. THE FURNACES AND MEASUREMENT OF TEMPERATURES

The furnaces and the thermometric equipment which were used in this investigation were modelled after those of the Geophysical Laboratory and the Lime and Gypsum section of the National Bureau of Standards.

Crystallizing Furnace

The crystallizing furnace was connected in series with three resistances having the values of 2, 2.75, and 6 ohms, respectively. The furnace-coil, consists of 100 grams of 0.8 mm. diameter iridium-free platinum wire containing 10% rhodium, and having a resistance of 3.28 ohms at zero degrees and 7.54 ohms at 1000°C.

Quenching Furnace[14]

This furnace and its attendant regulator employed in this study was patterned largely after a modification of the "Geophysical Thermostat" used by the National Bureau of Standards in phase rule problems. (Fig. 2.)

In the investigation of the stability of a phase at any one temperature it is necessary to provide a suitable means for the control of this temperature within the furnace and over an area of sufficient size to contain the charge. The workers at the Geophysical Laboratory have diligently experimented with all types of thermoregulating devices until they have developed, within the last ten years, extremely accurate and very sensitive controls for regulating furnace-temperatures.[15]

The essential features of the thermoregulator consist of a Wheatstone bridge, one arm of which consists of the heating-coil of the furnace, and a suitable arrangement of a galvanometer-relay with some type of a switching device to function under conditions of unbalance. See Fig. 3.

---

[14] I am indebted to Mr. F. F. Barry, Technician in the Geophysical Laboratory, for sketches from which the drawings of the furnaces were made.

[15] White, W. P., and Adams, L. H., *Phys. Rev.*, vol. **14**, pp. 44–48, 1919.
Roberts, H. S., *Jour. Wash. Acad. Sci.*, vol. **11**, pp. 401–409, 1921.
Roberts, H. S., *Jour. Opt. Soc. Am. & R. S. I.*, vol. **6**, pp. 965–977, 1922.
Adams, L. H., *Jour. Opt. Soc. Am. & R. S. I.*, vol. **9**, pp. 599–603, 1924.
Roberts, H. S., *Jour. Opt. Soc. Am. & R. S. I.*, vol. **11**, pp. 171–186, 1925.

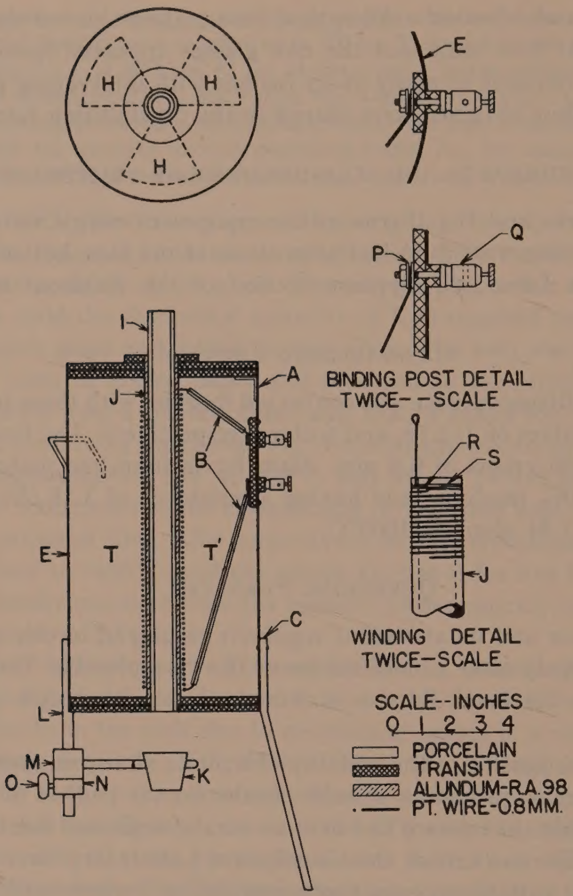


FIG. 2. The Geophysical Quenching Furnace.

A = Brass support.
B = Porcelain capillary tubes protecting the heating element.
C = Brass leg.
E = Sheet Brass.
H = Slots in transite cover.
I = Porcelain tube. (Not gas tight.)
J = Norton Alundum tube, special design.
K = Iron crucible containing mercury.
L = Brass rod.
M = Brass collar holding arm and crucible.
N = Brass clamp holding M in place.
O = Brass screw.
P = Heating element connection.
Q = Binding Post.
R = Loop in platinum winding about which string is wound to hold wire in place. Winding is painted with refractory cement and the string is burned away.

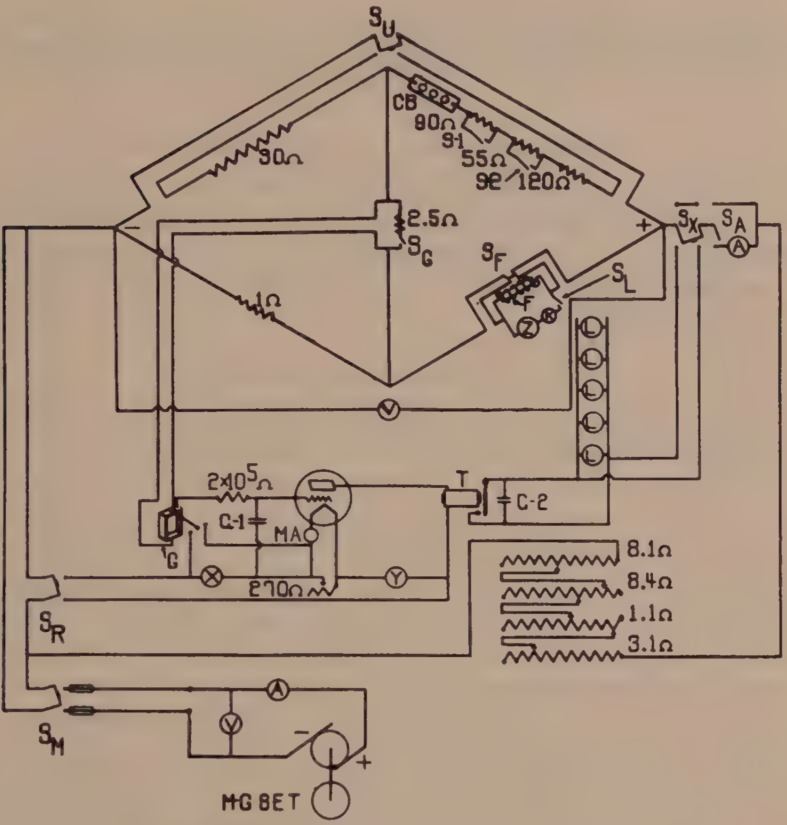


FIG. 3. Wiring diagram of the furnace and the thermoregulator.

S_A = single-pole, double-throw switch.
S_M = main switch, fused at 15 amperes.
S_R = switch throwing regulator into the circuit.
S_U = switch throwing in the upper arm of the bridge.
S_L = switch throwing tungsten filament bulb into the furnace circuit.
S_F = switch throwing the furnace into the circuit.
S_G = switch throwing galvanometer shunt in galvanometer circuit.
S_X = switch, when in the "*up*" position heats furnace independent of the upper bridge arm.
switch, when in the "*down*" completes the regulator circuit.
L = 75 watt, 32 volt, Mazda "C" lamp.
X = 60 watt, 120 volt, lamp.
Y = 40 watt, 120 volt, lamp.
Z = 50 watt, 32 volt, Mazda "C" lamp.
T = telegraphic relay. A = ammeter. V = voltmeter.
S-1, S-2 are shunting switches. MA = milliammeter.
F = platinum-wound furnace. K = 6 amperes, 120 v. fuse.
C-1 = condenser 0.01 mfd. G = galvanometer relay.

C-2 = condenser 0.1 mfd. Electron tube = CX-71 A.
M-G set = GE motor-generator set, 5 kw, 110 volt.
C B = continuous circuit click-box resistance of 999 ohms, used to change the temperature of the furnace.

ACCURACY OF THE TEMPERATURE CONTROL

The accuracy is dependent largely on the sensitivity of the regulating instruments and the insulation of the furnace. It is possible to control the "hot spot," a cavity of sufficient size to contain the charge, to within a maximum variation of 0.2°C. over a period of a day in the temperature range of 800–1200°C.

THERMOMETRIC MEASUREMENTS

Measurements were made with platinum: platinum-rhodium thermocouples calibrated at the following three fixed points:

NaCl	melting-point	800.4°C.
Au	melting-point	1062.6°C.
$CaMgSi_2O_6$ (Diopside)	melting-point	1391.5°C.

The NaCl and diopside were very kindly furnished by the Geophysical Laboratory. The gold was of very high purity made especially for thermometric calibrations. The microvoltages developed by the thermocouple were measured with a Wolff potentiometer and a very sensitive galvanometer. These measurements were all corrected with the use of a standard deviation curve constructed for the particular couple used.

The accuracy of the temperature determinations is within the usual limit for this type of work, namely 0.2°C. and their reliability is based on the frequent calibration. Although the temperature may be determined to within 0.2°C. the transformations are very sluggish and are only known to within 2°C. for most compositions. Thus the range within which the transformation occurs is accurately known to within ±0.2°C. on either side.

VI. REFRACTIVE INDICES AND THE FERROUS OXIDE CONTENT OF THE GLASSES

Petrographic-microscopic examination of the glasses for homogeneity may be accomplished by immersion of some of the powdered glass in a liquid of known refractive index, searching for reddish-brown patches of undissolved ferric oxide, hematite. After the thermal treatment had been sufficient to dissolve all of the ferric oxide and give a glass of uniform color, the refractive index was measured by the liquid immersion method. The accuracy of these measurements is ±0.002, each liquid immediately after use being checked on an Abbe total reflectometer.

Fig. 4 shows the relation between the refractive index and the ferric oxide content of the $K_2O \cdot 6SiO_2$ glasses. This relation is apparently linear along the $K_2O \cdot 6SiO_2$–Fe_2O_3 section.[16]

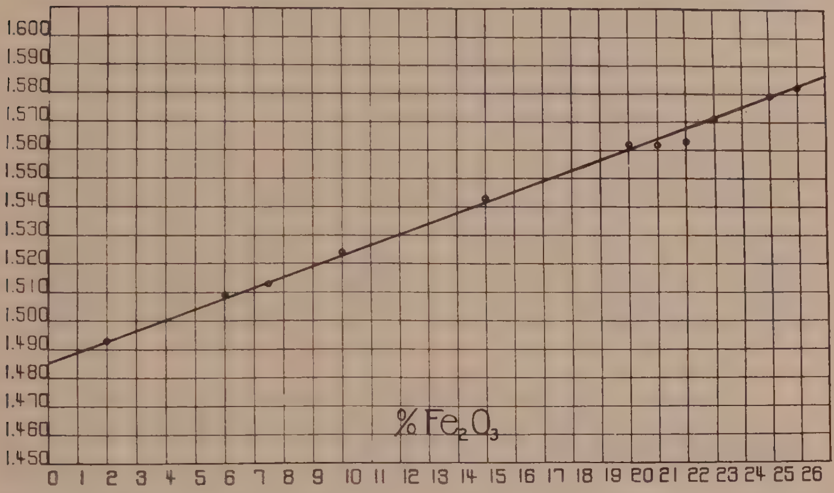


FIG. 4. The relation between the index of refraction and the iron content of the glasses. Total iron content expressed as Fe_2O_3.

It is to be remembered that these glasses contain small amounts of ferrous oxide (FeO). Studies by Hostetter and Roberts[17] indicate that the amount of dissociation of ferric oxide into ferrous oxide and oxygen in silicate melts, is relatively small, especially if the temperature of heating lies below 1200°C. Furthermore in the somewhat analogous system Na_2O–Fe_2O_3–SiO_2, Bowen, Schairer, and Willems[18] made a careful study of the state of oxidation of the iron in the melts and found that the FeO reaches a maximum of 1.09% in a melt containing 35% Fe_2O_3 held at 1175°C. At 26% Fe_2O_3 a charge held at 838°C. contained 0.39% FeO.

For the ferrous iron determinations of some of the glasses along this section, a 0.5 gram sample was placed in a platinum foil envelope and held approximately at the liquidus temperature for that composition, and for a length of time equivalent to that which was necessary in the quenching experiments. Since platinum has some effect on the state of oxidation of the iron,[19] the samples to be analyzed were subjected to the same conditions as those employed for the liquidus determinations. The analysis of the ferrous oxide content was made by the modified Pratt Method using a fused quartz flask. As this procedure has been adequately described elsewhere[20] it will not be repeated here.

---

[16] In the ternary system the isofracts are curved lines.

[17] Hostetter, J. C., and Roberts, H. S., *Jour. Am. Cer. Soc.*, vol. **4**, pp. 927–938, 1921.

[18] Bowen, N. L., Schairer, J. F., and Willems, H. W. V., *Am. Jour. Sci.*, vol. **20**, p. 418, 1931.

Table 2. Ferrous Iron Content of Representative Glasses

Composition of the glass				% FeO	°C. Temperature
$K_2O \cdot 6SiO_2$	SiO_2	Fe_2O_3	K_2O		
79.00%	62.63%	21.00%	16.37%	0.31±0.03	928.4
78.00	61.84	22.00	16.16	0.29±0.03	987.4
77.00	61.05	23.00	15.95	0.18±0.01	1,011.2
75.00	59.46	25.00	15.54	0.33±0.01	1,097.5

Ferrous Iron Content of Representative Glasses

Table 2 shows that the dissociation of Fe_2O_3, into FeO and oxygen, in silicate melts under laboratory investigation is of the order of magnitude indicated by the work of others.[12,13] The dissociation is, however, quite small, indicating that the departure in the more general quarternary system K_2O–Fe_2O_3–FeO–SiO_2 is not very great. We may therefore neglect its presence in our discussion without destroying the validity of the generalization, although it should be remembered that some FeO is present.

VII. QUENCHING EXPERIMENTS

The data presented in Table 3 represent, in general, only those critical quenches which establish the position of the liquidus and this group constitutes but a small portion of the numerous quenching experiments carried out in the laboratory.

[19] Sosman, R. B., and Hostetter, J. C., *Jour. Wash. Acad. Sci.*, vol. **5**, pp. 293–303, 1915.

[20] Soule, B. A., *Jour. Am. Chem. Soc.*, vol. **50**, p. 1691, 1928. Bowen, N. L., and Schairer, J. F., *Am. Jour. Sci.*, vol. **24**, pp. 178–213, 1932. *The procedure on page 185, was the one followed in this work.*

TABLE 3

Composition (weight per cent)			Time hrs.	Temperaature °C.	Final condition of the initially crystalline charge
K_2O	Fe_2O_3	SiO_2			
20.72	—	79.28		1133	Liquidus[21]
20.31	2.00	77.69	3½	1056	Glass
			1¾	1052	Glass plus very rare needles of tridymite
			3	1050	Glass plus tridymite
			3½	1009	Glass plus tridymite and pine-tree crystals of cristobalite
19.48	6.00	74.52	3	941	Glass
			3¾	939	Glass plus extremely rare tridymite
			4	931	Glass plus rare tridymite
19.17	7.50	73.33	15	904	Glass plus extremely rare cristobalite
			12½	900	Glass plus rare cristobalite, poorly distributed
18.65	10.00	71.35	5¾	838	Glass
			14	829	Glass plus extremely rare tridymite
17.61	15.00	67.39	21	836	Glass
			19	835	Glass plus extremely rare iron-orthoclase
17.09	17.50	65.41	33	920	Glass
			10	906	Glass plus rare iron-orthoclase
16.58	20.00	63.42	47	921	Glass
			23	920	Glass plus extremely rare iron-orthoclase
			22	917	Glass plus rare iron-orthoclase
16.47	20.50	63.03	74	933	Glass
			12	920	Glass plus exceedingly rare iron-orthoclase
			8½	917	Glass plus rare iron-orthoclase
16.37	21.00	62.63	3½	926	Glass
			5	921	Glass plus extremely rare iron-leucite
			4½	913	Glass plus iron-leucite, plus rare iron-orthoclase
16.16	22.00	61.84	9	992	Glass
			4	984	Glass plus extremely rare iron-leucite
			3½	926	Glass plus iron-leucite
			5	921	Glass plus iron-leucite, plus iron-orthoclase melting to iron-leucite

---

[21] Kracek, F. C., Bowen, N. L., and Morey, G. W., *Jour. Phys. Chem.*, vol. **33**, pp. 1857–1879, 1929.

TABLE 3.—*Continued.*

Composition (weight per cent)			Time hrs.	Temperature °C.	Final condition of the initially crystalline charge
K_2O	Fe_2O_3	SiO_2			
15.95	23.00	61.05	4	1013	Glass
			6	1007	Glass plus iron-leucite
			3	1004	Glass plus iron-leucite
15.54	25.00	59.46	3	1091	Glass plus extremely rare hematite, very close to liquidus
			4½	1052	Hematite plates common in glass
			3	1050	Glass plus fair amounts of hematite, iron-leucite rare
			3	1037	Glass plus abundant iron-leucite
15.33	26.00	58.67	1½	1265	Very rare hematite in glass, very close to the liquidus
			1½	1260	Rare hematite in glass
			2½	1051	Much hematite in glass
			1½	1020	Numerous plates of hematite in glass

Discussion of the Results. The charges containing 2, 6, 7.5, 20, 20.5, 21, 22, 23, 25, and 26.00% Fe_2O_3 were all crystallized from dry melts. The portion of the liquidus determined by these charges is indicated in Fig. 5, in heavy full lines.

The charges having 10, 15, and 17.5% Fe_2O_3 presented great difficulties in crystallization. Repeated trials extending over many months and at various temperatures failed to yield crystals, the glasses possessing little tendency to crystallize. It was necessary to resort to hydrothermal methods in order to bring about crystallization. This was accomplished by placing a small portion of the charge in a platinum thimble which, in turn, was placed into a fused quartz tube, about three-quarters of an inch in diameter and 12 inches long. A few drops of water were introduced along the side of the tube and the whole system sealed by fusing the end of the fused quartz tube. This was then placed in the crystallizing furnace and its temperature raised to some point below the liquidus. The resulting mass contained an abundance of small crystals but, owing to their great number, liquidus determinations proved difficult because of the greater uncertainty in the decision as to whether or not the charge had actually attained the equilibrium state. Runs, as long as 50 hours and more, were made in an attempt to attain equilibrium. Hence the liquidus temperatures, obtained on samples hydrothermally crystallized, are not as accurate as those obtained by the use

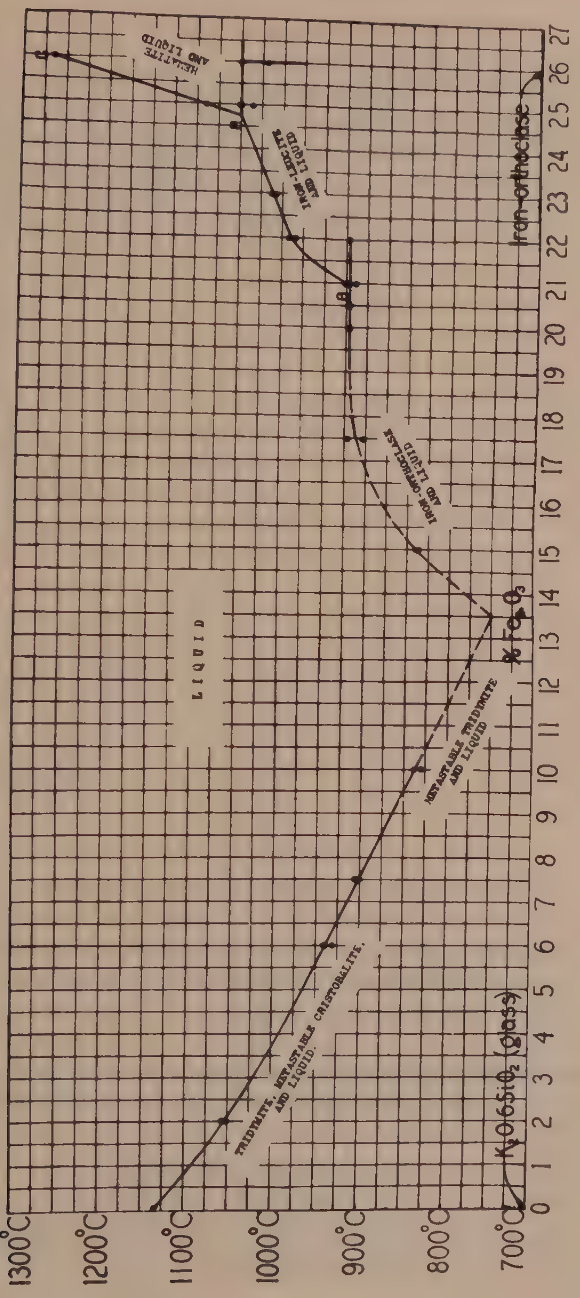

HEMATITE AND LIQUID
IRON-LEUCITE AND LIQUID
IRON-ORTHOCLASE AND LIQUID
LIQUID
METASTABLE TRIDYMITE AND LIQUID
TRIDYMITE, METASTABLE CRISTOBALITE AND LIQUID.
% Fe2O3
K2O.6SiO2 (glass)
Iron-orthoclase
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
1300°C
1200°C
1100°C
1000°C
900°C
800°C
700°C

FIG. 5.

of materials crystallized from dry melts, and this is indicated in Fig. 5, by the heavy dashed lines.

The $K_2O \cdot 6SiO_2$–Fe_2O_3 section now being considered is not a binary system in itself, but only a straight line section through the ternary system K_2O–Fe_2O_3–SiO_2, shown as the line X–Fe_2O_3 in Fig. 6. Therefore, the course of crystallization, for compositions located on the section, cannot be completely foretold without having recourse to a portion of the ternary system.

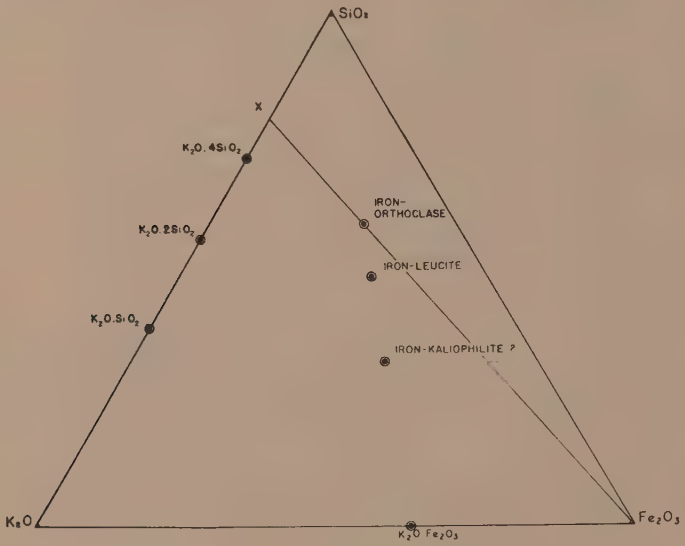


FIG. 6.

FIELD OF HEMATITE

The liquidus for the stability of hematite rises abruptly from point A (Fig. 5) and theoretically extends to the melting point of Fe_2O_3. In this connection Sosman and Merwin[22] state:

> The melting point of pure Fe_2O_3 is unknown, as it dissociates under atmospheric pressure of oxygen before the melting point is reached into oxygen and a solid solution of Fe_3O_4 in Fe_2O_3.

The curve was not investigated beyond 26% Fe_2O_3 or at temperatures exceeding 1265°C. because of the increase in the rate of the dissociation of ferric oxide and the consequent entry into the quaternary system, Fe_2O_3–FeO–K_2O–SiO_2. The field thus extends from 24.75% Fe_2O_3 to 100% Fe_2O_3.

---

[22] Sosman, R. B., and Merwin, H. E., *Jour. Wash. Acad. Sci.*, vol. **6**, pp. 532–537, 1916.

FIELD OF IRON-ORTHOCLASE

The stability boundaries for this phase extend from about 13.5% Fe_2O_3 over to 21% Fe_2O_3. Iron-orthoclase was not found to be metastable at temperatures exceeding 921°C. It must be emphasized at this point that the crystallization of iron-orthoclase has proved to be a rather difficult task. Experience has shown that in melts in which it is stable, particular attention must be paid to the constancy of the furnace temperature, and long periods of time, extending from three weeks to several months, are often necessary to merely induce the iron-orthoclase to crystallize. After the first nuclei are formed careful heating is very essential to the growth of the crystals.

At this time the actual fusion relations of iron-orthoclase cannot be given entirely. The present data indicate that iron-orthoclase melts incongruently to yield iron-leucite and a liquid at 920°C. Iron-leucite, in turn, decomposes to form hematite and a liquid. Hematite is the primary phase at the liquidus, disappearing at 1265°C.

FIELD OF IRON-LEUCITE

The field of stability for iron-leucite extends from 21% Fe_2O_3 over to 24.75% Fe_2O_3. Iron-leucite does not exist as a metastable phase at temperatures above 1050°C. on this section. In the melts, crystallized at temperatures at which iron-orthoclase is the stable phase, however, it was found that iron-leucite formed and further, it usually was the first of the two phases to form.

FIELD OF THE SILICA MINERALS

This field extends from 0.0 to 13.5% Fe_2O_3 along the composition coordinate and from 750°C. to 1130°C. along the temperature coordinate. The stable phase between 870°C. and 1130°C. is tridymite and this phase was observed in all melts. Between 870°C. and 750°C. the stable phase should be quartz but no signs of it were noticed, the liquidus being determined from the metastable tridymite present. In some charges, dendritic octahedra of metastable cristobalite were observed.

VIII. PROPERTIES OF THE CRYSTALLINE PHASES

IRON-ORTHOCLASE

The optical properties of the iron-orthoclase prepared by Hautefeuille and Perrey have been measured by Hautefeuille and Perrey,[2] Niggli,[3] and Gaubert[23] and found to be as follows: $\alpha=1.601$, $\beta=?$, $\gamma=1.609$; $\gamma-\alpha$

---

[23] Gaubert, R., *Compt. rendu du congrès des Sociétés Savantes de Paris et des Départments*. Sections des Sciences, pp. 402–408, **1925**.

$=0.008$. The compound is monoclinic and occurs in crystals resembling those of ordinary orthoclase. Its color is yellow. The optic plane is parallel to (010) and the extinction in (010) is 7° to 8° to the *a* axis. These indices are decidedly greater than the values for ordinary orthoclase. Thus we may assume that the refractive indices of orthoclase containing iron-orthoclase in solid solution should be raised somewhat.

In the routine determination of iron-orthoclase, as it occurs in the melts, its characteristic appearance as lath-shaped crystals was used to identify it. In melting, iron-orthoclase crystals are corroded more rapidly perpendicular to the length, and in such a manner as to produce an hour-glass structure.

The identification of this compound was made by comparison of the *x*-ray diffraction patterns of powders of iron-orthoclase and ordinary orthoclase. The replacement of aluminum ($Al\ 3^+$) by iron ($Fe\ 3^+$) should cause a decrease in the spreading of the lines on the powder photograph of iron-orthoclase. That is, the lines should move progressively in toward the zero beam, indicating an increase in the size of the lattice. This follows from a consideration of the ionic radii,[24] $(Al\ 3^+)=0.57$, $(Fe\ 3^+)=0.67$. The actual powder photographs verify this.

IRON-LEUCITE

Iron-leucite occurs as small subhedral to rounded grains which are yellow in color. The grains exhibit low grey interference colors, and this double refraction can be detected more easily by the use of the gypsum test plate. The optical properties measured on Hautefeuille's original material by Gaubert[23] are as follows:

$n=1.619$. Birefringence greater than the
aluminous variety.

The identity of this compound with the ordinary leucite with reference to the molecular ratios of the constituent oxides, 1:1:4, and similarity of crystalline structure is made very evident by a comparison of their respective *x*-ray powder diffraction patterns. Except for the progressive movement of the lines toward the zero beam, the patterns are in good agreement. As was stated in connection with the *x*-ray studies of iron-orthoclase, the lattice spacing is larger as would be expected from a consideration of the ionic radii. Along this section, the iron-leucite crystals developed as subhedral grains which have a strong tendency to arrange themselves in star-like or ray-like patterns.

Optical measurements on a well crystallized preparation of the composition of iron-leucite showed the grains to possess an intricate polysynthetic twinning, resembling very closely the twinning of ordinary leucite. The interference colors are predominantly low greys, although in large fragments straw-yellow appears. The double refraction is weak. The index of refraction of this material is 1.619 in agreement with Gaubert's measurement.

---

[24] Hassel, O., *Kristallchemie*, p. 12, Leipzig, 1934.

Hematite

The hematite observed was in the form of typical crystals, consisting of translucent hexagonal plates usually having a reddish color, but in very thin sheets they were quite often yellow. Since the properties are so characteristic and cannot be confused with those of other compounds, and since the index is so high as to be very difficult of measurement, the value of its optical constants was not determined.

Silica Minerals

The tridymite crystals exhibit the characteristic hexagonal platy structure. Plates standing on end, so as to give a needle-like appearance, are easily observed because of the birefringence. Cristobalite occurs usually in characteristic dendritic growths.

IX. DISCUSSION OF THE EVIDENCE FOR THE EXISTENCE OF AN IRON-ORTHOCLASE MOLECULE IN FELDSPARS.

The feldspars as a group constitute about sixty per cent of the earth's crust. As a result of their great abundance and development as crystals there naturally has accumulated a vast amount of physical and chemical data concerning them.

The major constituents of the feldspars, silica, lime, soda, potash, and alumina, have been carefully investigated from an experimental standpoint. Tschermak's classic interpretation of the isomorphic relations of the plagioclase feldspars has been experimentally verified by the work of Day and Allen,[25] and later by Bowen.[26] The Geophysical Laboratory is extending its experimental work in the systems involving the three fundamental molecules, orthoclase, albite, and anorthite.

With the exception of the work by Pentti Eskola[27] on the barium and strontium feldspars little has been done with the minor constituents, viz., lithium, ferric iron, and cesium and rubidium.

In the light of the preceding investigation it was considered appropriate to review the literature concerning the existence of ferric feldspars and this has been done, but with no attempt at completeness.

---

[25] Day, A. L., and Allen, E. T., Isomorphism and the thermal properties of the feldspars: *Carnegie Inst. of Wash., Pub. No.* **31**, 1905.

[26] Bowen, N. L., The melting phenomena of the plagioclase feldspars: *Am. Jour. Sci.*, vol. **35**, pp. 577–599, 1913.

[27] Eskola, Pentti, The silicates of strontium and barium: *Am. Jour. Sci.*, vol. **4**, pp. 331–375, 1922.

CHEMICAL AND PHYSICAL DATA

The analyses of feldspars, both of the alkali and plagioclase varieties, have in most cases yielded oxides of iron in determinable amounts. Some mineralogists have considered all of this iron to be due to contamination of the feldspars by foreign inclusions, and consequently not essential to the composition of the mineral. In many cases this is probably true to some extent. Others have attributed the presence of the iron oxides to weathering phenomena.

On the other hand, this is not always the case, for many writers have noticed that in the sunstone variety of feldspars there is an abundance of hematite crystals and they have demonstrated that the definite orientation of the plates, which give to these minerals their attractive chromatic effects, is due to an exsolution process.

The most outstanding example of a ferriferous orthoclase is the yellow, homogeneous orthoclase from Madagascar. A series of analyses given by Lacroix[28] and Seto[29] are listed in Table 4.

TABLE 4. ANALYSES OF FERRIFEROUS-ORTHOCLASE

	1	2	3	4	5	6
SiO_2	64.25	64.21	64.26	64.19	63.99	64.76
Al_2O_3	16.06	17.78	17.23	16.62	18.02	17.98
Fe_2O_3	2.93	1.15	2.16	2.88	0.97	1.18
FeO	0.25	0.09	0.18	0.18	—	0.09
MgO	none	none	none	—	—	0.08
CaO	tr.	0.07	0.05	—	0.50	0.16
BaO	—	—	—	n.d.	0.06	n.d.
K_2O	16.15	15.21	15.55	15.81	14.32	15.39
Na_2O	0.44	0.42	0.38	0.34	1.86	1.07
H_2O+	—	—	—	—	0.51	0.20
Sum	100.08	98.93	99.81	100.02	100.23	100.91

Analysis	*Analyst*	*Comments*
1	K. Seto	Optically examined by Kozu.
2	K. Seto	Lighter in color. The analysis 2, either contains a typographical error, or was incorrectly summed, the total given being 99.63.
3	K. Seto	Color intermediate between 1 and 2.
4	Boiteau	Original analysis, for Lacroix.

---

[28] Lacroix, A., *Minéralogie de Madagascar*, Paris, vol. **1**, pp. 557–562, 1922.

[29] Seto, K., *Science reports, Univ. Tohoku,* (III), vol. **1**, pp. 221–223, 1923.

5	Boiteau	Colorless adularia associated with yellow orthoclase in the pegmatite.
6		Analyzed specimen in the collection of the University of Rochester.

In Table 5 these analyses of the ferriferous orthoclase have been calculated into their component molecules, assuming all of the iron to be present in the ferric state. Actually, the amount of ferrous iron in the analyses is small and would not cause a great change in the final results. Theoretically these sums should total to 100%, but incompleteness in analysis, or inaccuracies in methods, etc., cause slight deviations.

TABLE 5. CALCULATION OF THE ANALYSES INTO THE VARIOUS COMPONENT FELDSPARS

	1	2	3	4	6
Orthoclase	84.20	85.44	83.62	82.60	86.74
Albite	3.72	3.55	3.21	2.87	9.05
Anorthite	—	0.35	0.25	—	0.79
Iron-orthoclase	12.35	4.81	9.08	11.85	4.93
Totals	100.27	94.15	96.16	97.32	101.51
Analyses Totals	100.08	98.93	99.81	100.02	100.91

These data offer support to the view that orthoclase and iron-orthoclase are isomorphous. The maximum concentration of the iron-orthoclase so far reported is about 12%.

The physical properties which have been determined on this Madagascar feldspar include optical and spectrographic studies.

The indices of refraction of the specimens whose analyses are given in Table 5 are listed below:

Analysis 1 $\alpha=1.5216$, $\beta=1.5259$, $\gamma=1.5261$,
2 $\alpha=1.5185$, $\beta=1.5225$, $\gamma=1.5239$,
4 $\alpha=1.5197$, $\beta=1.5248$, $\gamma=1.5253$, $2V_{Na}=34°06'$.

These values show slight increases over pure orthoclase, which would be expected in the substitution of iron for aluminum.

The Transmission of Light through Yellow Orthoclase. Some unpublished notes by Dr. E. F. Holden[30] on the ferriferous feldspar from Madagascar are given with the permission of Professor W. F. Hunt. The data are given in Table 6 and Plotted in Fig. 7.

This spectrographic data by Holden demonstrates that the iron is in the ferric state and as such must proxy for aluminum.

---

[30] Mineralogical Laboratory, University of Michigan.

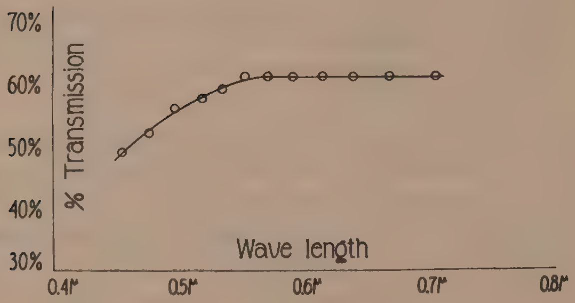


FIG. 7.

This unusual variety of orthoclase from Madagascar, is yellow and transparent. It has been described by Lacroix who published an analysis by Boiteau, indicating 2.88% ferric oxide. The curve in Fig. 7, from data obtained on a cleavage plate one cm. in thickness, shows that the absorption of light by this mineral is like that of ferric compounds,[31] which exhibit no bands but simply show a general absorption of the light in the blue end of the spectrum. The color may be ascribed to large amounts of ferric iron.

TABLE 6

Wave length	*Percentage of Transmission*
.704	61%
.668	61
.639	61
.615	61
.592	61
.572	61
.554	61
.537	59
.520	57.5
.498	56
.478	52
.457	49

OCCURRENCE OF FERRIFEROUS FELDSPARS

The Occurrence of a Ferriferous-Orthoclase. The only field occurrence of what may be termed an iron-orthoclase: orthoclase mineral is the one reported by Lacroix.[28] At d'Itrongay, Fianarantsoa, Madagascar, a gem-like yellow to yellow-gold orthoclase occurs in a pegmatite associated with adularia, transparent zircon, and *diopside*. This group of minerals, occurring in fairly large crystals in a pegmatite, is distinctly unique. Further studies should lead to some interesting conclusions concerning the physico-chemical environment at the time of injection. It is to be noted that the associates include just those with which we should expect to find iron-orthoclase compatible, *especially the diopside*. Washington[32] has pointed out from a graphical study of numerous analyses of igneous rocks that "magnesia and the iron oxides tend to go together."

---

[31] Holden, E. F., *Am. Mineral.*, vol. **10**, pp. 127–128, 1925.

[32] Washington, H. S., *Jour. Franklin Inst.*, vol. **190**, p. 792, 1920.

Occurrence of Other Iron-Bearing Feldspars. The classic examples of feldspars containing, at the time of their separation, iron oxides in solid solution are the aventurine feldspars. Andersen[33] in particular has made a rather extensive study of aventurine feldspars and his conclusions concerning the hematite are very instructive (Note: the words in italics are the writer's):

> The formation of aventurine feldspars by unmixing in the solid state may be conceived as follows: the feldspar crystals were, at the time of their separation, wholly, or in part homogeneous and contained small amounts of Fe_2O_3 in solid solution, either as hematite or as *a constituent of a ferric compound*. By a change in the exterior conditions prevailing at the time of formation, e.g. change in temperature, the equilibrium of the solid solution may be disturbed in such a way that Fe_2O_3 can no longer be held in solution, but must separate in individual crystals . . . (*and*) in such a manner that the hematite lamellae have separated along structural planes (translation planes) of the feldspar.

Some peculiar distributions of iron oxides in feldspars have been described in the literature. Thus Schairer[34] in an analysis of brown feldspar from Portland, Connecticut, points out that small red flakes of iron oxide occur *only* in the *microcline* of a microcline-albite microperthite, and that their distribution is irregular. Further, Lacroix[35] describes a violet colored orthoclase occurring in a syenite pegmatite from Sabotsy (to the west of Fianarantsoa), Madagascar, and states that its color is due to fine inclusions of magnetite. He makes no statement regarding their origin in the orthoclase. The results of Andersen's experiments (p. 376) may, however, apply here.

> (1) Cleavage piece with numerous transparent hematite lamellae heated for one hour at 1260°: The feldspar remained birefringent throughout with outlines sharp as before the heating; colorless; transparent, but somewhat dim. All hematite inclusions disappeared.
>
> (5) Piece from exp. (1) heated for twenty-four hours at about 1050°: Feldspar milk white, dull, full of very fine black dust.
>
> (6) Cleavage piece with numerous hematite lamellae heated for one-half hour at 1235°: Feldspar birefringent; colorless; somewhat dim, but still transparent. All hematite disappeared.

In pegmatites no such temperatures prevail but long continuous heatings at much lower temperatures may be able to bring about the same reactions.

Evidence from Synthetic Studies

Experiments of Hautefeuille and Perrey. As early as 1888, Hautefeuille and Perrey[2] attempted to prepare an analogous iron-orthoclase molecule from dry melts and failed. They then resorted to the use of mineralizing agents and succeeded in producing iron-orthoclase, iron-leucite, and hematite at will, by merely controlling the proportions of the components employed. Their comments are worthy of repetition:

---

[33] Andersen, Olaf, *Am. Jour. Sci.*, vol. **40**, pp. 351–399, 1915.

[34] Schairer, J. F., *Proc. Yale Min. Sc.*, vol. **2**, pp. 20–21, 1924–1925.

[35] Lacroix, A., *Minéralogie de la France*, vol. **5**, p. 28, Paris, 1913.

> The exclusive production of iron-leucite characterizes the primary phase of the mineralization. But the nature of the products which arise subsequently, is essentially dependent upon the proportions of the materials used and this amount can ensure the stability of the leucite, or determine, on the other hand, the appearance of hematite crystals or of feldspar crystals.

Evidence from the Present Studies. From the experiments conducted in this laboratory, we may conclude that the existence of the iron-orthoclase molecule has been definitely confirmed. Its fusion relations are quite complicated, originating in the incongruent melting of iron-orthoclase to iron-leucite and a liquid, followed by the subsequent incongruent melting of iron-leucite into hematite and a liquid.

From a study of Fig. 5, it is quite apparent that iron-leucite would probably be the primary phase of mineralization in the attempts of Hautefeuille and Perrey to produce iron-orthoclase. The diagram also explains their statements regarding the appearance of hematite or iron-orthoclase depending upon the adjustment of the composition.

It is not surprising that these early investigators failed to discover the phenomenon of the incongruent melting of iron-orthoclase; since the recently developed quenching method, employed in this study for the examination of the phasal relations, is the only method available at present to indicate incongruent melting.

In this investigation iron-orthoclase was prepared for the first time from a dry melt, namely, without the use of mineralizing agents.

INTERPRETATIONS

(A) *The Ferriferous Plagioclases.*

Andersen[33] has suggested that the feldspars contain small amounts of Fe_2O_3 in solid solution either as hematite, or as a constituent of a ferric compound.

Niggli[3] writes concerning these hematite inclusions as follows:

> It does not appear to me to be a simple weathering phenomenon but rather an unmixing of the Fe_2O_3 originally existing in isomorphic replacement of the Al_2O_3, and we can suppose that this unmixing can begin on cooling at approximately 450°C.

Wherry[36] does not consider the replaceability of iron in the feldspars practicable, and uses it as one of the criteria for choosing a system to explain the isomorphism of the feldspars. He states:

---

[36] Wherry, E. T., *Am. Mineral.*, vol. 7, pp. 113–121, 1922.

> No explanation of the isomorphism in question (atomic isomorphism) can be accepted if it does not account for the molecular volume relations, *the practical non-replaceability of aluminum by iron*, and very limited isomorphism of orthoclase and carnegieite with anorthite . . . .

Holden[30] commenting on the work of Andersen noted that all the aventurines examined were either plagioclase or microcline, and suggested that the solid solution of the iron component, in the case of the aventurine, was insoluble at low temperatures, whereas in orthoclase it could remain in a stable state, as in the Madagascar orthoclase.

(B) *The Ferriferous Orthoclase.*

Lacroix considered Fe_2O_3 as replacing Al_2O_3 in the yellow orthoclase from Madagascar and attributed the attendant change in properties to this substitution. Recently, in a review of the life and works of Hautefeuille, Lacroix[37] writes concerning the compounds prepared by him (Hautefeuille) as follows:

> . . . a leucite and a yellow orthoclase in which the aluminum oxide is replaced by ferric oxide, since he has produced this special feldspar, I have discovered from Madagascar, a yellow-gold orthoclase which contains several per cent of it.

Seto[29] has carried out some interesting thermal experiments with the Madagascar ferriferous orthoclase and his results are pertinent to this discussion. He heated a crystal for one hour at 1200°C., which is higher than the temperature applied by Lacroix,[38] and observed no change in color. Upon heating perthite, this temperature proved sufficient to easily oxidize the iron, and he concludes that the iron in perthites is a "subordinate ingredient." On the basis of these experiments he concludes:

> that the iron in the yellow feldspar is combined in a stable form with other essential components of the minerals. So far as our investigation goes, it is uncertain at present in what position the iron atom is situated in the space lattice of the feldspar. But it appears most likely that the ferric iron is replaceable for alumina.

The conclusion thus drawn by Seto from his thermal experiments seems to strengthen the views of Holden regarding the possibility of a greater stability of the iron in orthoclase solution relations than in plagioclases and microcline.

Barth[39] also believes in the existence of an iron orthoclase. Unfortunately, in this discussion there is a misprint and he has corrected this in a written communication to the writer:[40]

---

[37] Lacroix, A., *Figures de Savants*, vol. **1**, p. 85, (Paris), 1932.

[38] Lacroix, A., *Compt. rendus*, vol. **155**, p. 672, 1912.

[39] Barth, T. W. F., *Norsk. Geol. Tidsskrift*, vol. **12**, pp. 57–72, 1931.

[40] Written communication, dated January 9, 1935.

> . . . I see that there is a peculiar misprint in the formula of the iron feldspar p. 59. Of course $Fe^{\cdot\cdot\cdot}$ should proxy for $Al^{\cdot\cdot\cdot}$ so that the formula becomes $KFeSi_3O_8$. I do not know how the misprint happened, for I have never had any other idea about the replacement in feldspar. Also in Seto's paper (which is quoted by me) only the substitution of $Fe^{\cdot\cdot\cdot}$ for $Al^{\cdot\cdot\cdot}$ is considered.

The views of recent workers thus indicate that for the most part they are in agreement with the idea that at least partial isomorphism exists between the ferric feldspars and the alkalic and plagioclase varieties. It is not likely to be of the same extent in each type, but probably is more pronounced in the case of orthoclase. In the plagioclases and microcline, the isomorphic replacement becomes unstable at lower temperatures and exsolution occurs with hematite separating out as a new phase. The term ferric feldspar suggests several possibilities: iron-orthoclase, iron-albite (?), iron-anorthite (?), and iron-microcline (?).

Iron-albite (?) $Na_2O \cdot Fe_2O_3 \cdot 6SiO_2$. An examination of the ternary system, Na_2SiO_3–Fe_2O_3–SiO_2,[18] shows that a compound corresponding to that composition has no place on the liquidus of the system, and its synthesis with fluxes has not been reported. This does not preclude the possibility of its existence, for catalysts and pressure might induce its formation, but its existence is very doubtful.

Iron-anorthite (?) $CaO \cdot Fe_2O_3 \cdot 2SiO_2$. So far no synthesis of this compound has been reported. The only suggestion of its existence is contained in the work of Day and Allen.[25]

Iron-microcline (?) $K_2O \cdot Fe_2O_3 \cdot 6SiO_2$. Hautefeuille and Perrey[2] believed that they had synthesized an iron-microcline (?).

Iron-orthoclase $K_2O \cdot Fe_2O_3 \cdot 6SiO_2$. This compound has been definitely shown to exist. Field occurrences support the isomorphism of iron-orthoclase with ordinary orthoclase to the extent of about 12% iron-orthoclase.

Thus the chemical, physical, and synthetic data establish the existence of an iron-orthoclase molecule and substantiate the view that in the case of the Madagascar feldspar we are dealing with a solid-solution of iron-orthoclase in orthoclase. Just what the composition of the ferric feldspar, which was present before exsolution, in the aventurines may have been, we do not know. It seems that it is not unreasonable to suppose that the hematite in the aventurines was originally present, in part, as a solid-solution of iron-orthoclase in plagioclase. Alling[41] has expressed a similar view.

---

[41] Alling, H. L., *Jour. Geol.*, vol. **31**, p. 368, 1923.

X. ACKNOWLEDGMENTS

This investigation was made possible by the appointment of the author to a University Fellowship and through two grants, for equipment, from the University of Michigan Faculty Research Fund.

I wish to express my sincere thanks to Dean E. H. Kraus and Professors W. F. Hunt and A. B. Peck of the Mineralogical Laboratory for their advice, assistance, and encouragement in the execution of this problem. I am indebted also to Drs. J. F. Schairer and N. L. Bowen of the Geophysical Laboratory for suggesting the system and for their continued interest and instructive criticism; to Dr. J. W. Greig of the same laboratory for his timely suggestions; to Dr. L. S. Wells of the Lime and Gypsum section of the National Bureau of Standards who furnished a number of useful hints regarding the operation of the furnaces; and to Dr. Olaf Andersen of the Research Laboratory of the United States Steel Corporation who kindly read the manuscript and offered many helpful suggestions.

Mineralogical Laboratory,
University of Michigan.

A NEW PROPERTY OF MATTER: REVERSIBLE PHOTOSENSITIVITY IN HACKMANITE FROM BANCROFT, ONTARIO

O. Ivan Lee, *Jersey City, New Jersey.*

Abstract

Hackmanite from near Bancroft, Ontario, undergoes a remarkable color intensification following brief exposure to a suitable source of ultra violet light, including the argon bulb, iron spark, carbon arc with cored carbons and quartz tube mercury vapor lamp, changing from colorless or pale pink to a raspberry shade or deep violet. With the argon bulb, however, a much longer exposure is required. By means of selective filters, the exciting radiation has been determined as being not longer than about 4800 A.U., and extending down to about 2250 A.U., and perhaps lower. The induced color slowly fades in darkness to a bright red violet, but fades rapidly and nearly completely on exposure to strong light, the radiation responsible for the reversal phenomenon having a peak in the visible region in wave lengths shorter than yellow, although extending to 7500 A.U. Longer wave lengths up to 39000 A.U. having no effect.

The intensification and reversal may be repeated indefinitely, and is suspected of being connected with the known presence of a trace of manganese, spectrographic analysis disclosing 0.001% of this element. However, the presence of the extraneous elements Li, Ga, Pb and Nd, was also revealed, as well as traces of Be, Ba, Sr, and perhaps P, some of which may also be involved in either its photosensitivity or luminescent properties, or both. The pink sodalite thus exhibiting color intensification and reversal, fluoresces a salmon color when viewed with the aid of a Corning Red Purple Corex A No. 986 filter, and phosphoresces sky blue, but colorless undetermined associated minerals may phosphoresce bluish, yellowish, greenish, orange, or not at all. It is suggested that both the partial recovery of color in darkness following reversal, and the partial reversal in darkness following excitation, are both due to concomitant phosphorescence having compound radiations. Some reversibly photosensitive and thermosensitive substances of related interest are discussed.

Introduction

Several years ago while examining miscellaneous minerals for evidence of fluorescence and phosphorescence with an ultra violet lamp of the iron spark type, a specimen of hackmanite, a member of the sodalite group, from near Bancroft, Ontario, was tested. The specimen was a very poor one, and no particular fluorescence or phosphorescence was noted, but in the light the impression was obtained that violet red spots had appeared as a result of the exposure to ultra violet light, which had not previously been present. However, as the spots appeared to be permanent, and the original appearance of the mineral had not been carefully noted, the matter was not then further investigated. Recently, however, through the kindness of Dr. T. L. Walker, Director of the Royal Ontario Museum of Mineralogy, Toronto, Canada, a far superior specimen of hackmanite from the same locality was received. It was well tinted in patches of pink, not unlike that of rose quartz, and was described by the sender as being of much better color than was available until recently, but as not losing its color in such a spectacular way, sometimes within a few seconds after being exposed to light. Dr. Walker interpreted this to mean that this recent material contained considerable more of the pink mineral than the original lot described by him some years ago,[1] and expressed the belief that it would lose practically all its color after a few days exposure to light, as has been previously recorded by himself and others. The mineral associates from this locality are nepheline, cancrinite, calcite, plagioclase, essonite, diopside and vesuvianite. The fact that hackmanite, formerly known as pink sodalite, fades on exposure to light, has been known for almost a hundred years, although apparently the alleged phenomenon was regarded with some scepticism by mineralogists until the twentieth century.

The original pink sodalite collected by Giesecke between 1806 and 1808 in Greenland, is thus described by Allan:[2] "Its color is green unless freshly fractured, when it presents a brilliant pink tinge, but this on exposure to light goes off in a few hours."

Vredenburg[3] in describing certain rocks containing sodalite and nepheline from Kishengarh State in Rajputana, refers to a peculiar sodalite as follows: "Moreover, some of the sodalite exhibits an extraordinary phenomenon hitherto unrecorded in any mineral. While some of the specimens are of a bright blue color similar to that of the mineral from many other localities, others appear under ordinary conditions transparent and colourless. But some of these colourless fragments when kept in the dark for a fortnight or three weeks assume a pink color which disappears rapidly on exposure to bright daylight, and almost instantaneously in direct sunshine.

"The phenomenon is particularly brilliant when the rock is first broken in the field, and the large blocks of elaeolite (some of which are over a yard wide) appear, on fracture, as if suffused with blood. The colour seems to re-appear more completely in some specimens than in others, for while the disappearance of the colour is very rapid, its re-appearance which constitutes the most remarkable feature of the change, is very slow. The precise nature and cause of this peculiar phenomenon are at present unknown."

It is evident that Vredenburg observed not only a striking fading (reversal) of the original color, but likewise noted a slow and inexplicable color recovery in darkness.

Borgström[4] described this variety of sodalite from the nepheline rock called tawite in the Lujaur-Urt on the Kola Peninsula, as hackmanite, and remarked that it was bright red violet in color, bleached rapidly in daylight, and contained 0.39% of sulfur equivalent to 6.23% of ultramarine.

Finally, Walker and Parsons[1] recorded the following of the hackmanite from Dungannon Township near Bancroft, Hastings Co., Ontario: "On freshly-broken surfaces of the rock—one frequently observes spots of fine pink colour, which for the most part disappears completely in direct sunshine in from ten to thirty seconds. When placed in the dark the colour gradually returns, but according to our observation it never becomes as bright as at first, even after being protected from light for one week."

Their analysis gives also "Mn trace" but no sulfur (difference from Borgström's hackmanite), and they conclude with respect to the color changes: "Nothing of a fundamental nature has as yet been determined in regard to the colour change, except that it is due to some part of the visible spectrum. Exposure to x-ray fails to bring about the change in colour." They regarded the occurrences in Greenland, Kola, Kishengarh and Bancroft as being closely related.

Effect of Ultra Violet Light from the Iron Spark

The new specimen was accordingly subjected in darkness to intense excitation from the iron spark discharge, being held close (2 cm.) to the gap for ten seconds. A reddish violet coloration was noted but attributed to fluorescence. This was followed by a general, distinct and rather persistent bluish phosphorescence described by Brown.[5] On turning on the light, however, the author was amazed at the change which had come over the mineral. It was splashed with broad patches, streaks and spots of a rich and beautiful raspberry-red color, the acquired hue having little in common with the original pink color still visible on the unexposed areas of the specimen. This color appeared to be well retained in darkness, although it was of lessened intensity after being kept thus overnight, and given time, presumably would slowly fade to deep pink. In light of ordinary intensity indoors, the acquired color was found sufficiently permanent to admit of prolonged examination. In this way, it was determined that the areas of the original pink mineral coincided with those acquiring the permanganate color under ultra violet radiation, and likewise exhibiting a bright blue phosphorescence, similar in color, although not in intensity, to that of the remarkable phosphorescent manganiferous calcite from the Chisos Mountains, Brewster County, Texas.* However, there was an over-all fainter bluish phosphorescence throughout the whole area exposed, which may arise from invisible deeper areas. On holding the mineral close to an ordinary frosted (60 watt) electric lamp for a brief interval (30 seconds), the deep induced color rapidly faded until the original appearance was restored, when the process could be repeated. So far as the writer knows, this is the first instance of induced reversible photosensitivity in a mineral, the general behavior indicating that the color is intensified by exposure to certain frequencies in the ultra violet, and the induced color is in turn reversed by the higher frequencies in the visible spectrum.

---

* Following excitation in the dark with the iron spark for 10 seconds at 2 cm., the phosphorescence of this calcite suffices to read news type for five seconds.

Brown[5] also tested the fluorescence of this Ontario hackmanite under ultra violet (as well as under red (heat)) radiation, using a quartz-mercury lamp provided with a filter of Wood's glass to cut off visible light, only 3000–4000 A.U. being transmitted. However, he failed to note any visible change other than a "pink" fluorescence and a "white" phosphorescence induced by heating below red heat in a dark room. This latter effect was photographed and appears to be similar or identical to the general phosphorescence excited by ultra violet radiation.

Effect of Corning Red Purple Corex A No. 986 Filter

The visible light from the iron spark was cut off through the interposition of a Corning Red Purple Corex A No. 986 filter, and the mineral again tested. A very beautiful general fluorescence was seen whose color is best described as salmon. In addition, large areas colored cobalt blue were observed, as well as other areas having a rich purple color. The blue areas are doubtless identical with the sodalite from Bancroft, mentioned by Brown[5] as fluorescing in that color, while the purple patches may be in part due to some other non-fluorescent white mineral colored by the transmitted light. Phosphorescence was perceptible but very noticeably weaker, and the same was true of color intensification. Further testing demonstrated that the mineral fluorescing in blue lacked any visible power of phosphorescence or of color intensification.

Excitation Under the Carbon Arc

The hackmanite was tested by exposure at 18 cm. to an ultra violet "Health" lamp rated at 1000 watts, using "Eveready" (cored), "Super Tan" carbons at 9 amperes. The characteristic color was rapidly developed, any reversing effect due to the abundant light evidently being more than compensated for by the high intensity of the ultra violet emitted. Consequently, interposition of the Corning Red Purple Corex A No. 986 filter made little perceptible difference.

Excitation Under the Argon Bulb

Preliminary experiments with this source of excitation were negative, but it was found that by sufficiently extending the time of exposure, very satisfactory results could be achieved. The following tabulated results were achieved in a dark room with the specimen in contact with the bulb, the usual fluorescence being noted:

Time of exposure in minutes	*Degree of intensification*
2	Very faintly colored
4	Slightly colored
8	Well colored
16	Strongly colored
32	Very deeply colored

It is not certain whether this reluctance is due to the low relative intensity of the argon bulb,[6] to the inability of the glass to transmit short waves less than 3000 A.U.,[6] or to both these factors.

EXCITATION UNDER QUARTZ TUBE MERCURY VAPOR LAMP

This was made with a Hanovia lamp having a 6″ tube and rated at 1000 watts, protected by a lead shield. The hackmanite was placed 23 cm. below the lamp and pronounced color intensification readily occurred. The Corning Red Purple Corex A No. 986 filter visibly interfered with excitation, however. This was demonstrated by exposure after covering part of the specimen with the filter, the difference in color intensity being readily apparent. Color intensification was (almost) completely inhibited by interposition of ordinary window glass.

Although Brown[5] utilized this source of ultra violet illumination, he failed to note any color intensification in hackmanite from this locality although the mineral earned special mention because of its unusual photo-luminescent properties. Possibly any color intensification developed was confused with the red violet color transmitted by the filter, and as over 200 specimens were examined, presumably in a dark room, the new phenomenon easily escaped observation.

EFFECT OF VARIOUS FILTERS ON REVERSAL

Following intensification by ultra violet light from the iron spark, the effect of various filters on the color reversal was studied by placing them between the excited mineral and an ordinary frosted 60 watt electric light. The only filter tested which completely inhibited reversal was a Corning Heat Transmitting No. 254, although Red Purple Corex A No. 986 and the yellow, orange and red filters visibly interfered with reversal, the effect of the last three increasing in the order stated.

TABULATION OF EXPERIMENTS ON REVERSIBLE PHOTOSENSITIVITY OF HACKMANITE INCLUSIVE OF EFFECTS OF VARIOUS FILTERS

Filter Used (C=Corning)		None interposed	C Clear Corex A 980 3 mm.	C Red Purple Corex A 986 2.5 mm.	C H.R. Clear Corex D 970 2 mm.	C Chemical Pyrex 2 mm.	C Clear Blue Fluorescing 014 3 mm.	Window Glass 1.5 mm.	C Yellow Noviol C 338 3.5 mm.	C Orange 349 3.5 mm.	C Signal Red 243 3.9 mm.	Clear Corex A Water Cell 10 mm.	C Heat Transmitting 254 3.5 mm.
Approximate Transmission in A.U.			2250–27000	2500–4250; 6500–10750	2650–35000	2800–35000	3200–39000	3225–39000	4800–45000	5360–45000	6170–45000	±3300–14000[7]	7500–39000
Excitation with	Quartz Tube Mercury Vapor Lamp; 10 cm.; 60 sec.	+	+	+ (weaker)	+ (weaker)	+ (weaker)	+ (much weaker)	+ (very weak)	–	–	–	+	–
	C Type Carbon Arc; 10 cm.; 60 sec.	+	+ (weaker)	+ (stronger)	+	+ (weaker)	+ (very weak)	+	–	–	–	+	–
	Iron Spark; peak at 2600 A.U.; weak in long U.V.; 2 cm.; 10 sec.	+	+	+ (weaker)	+ (weaker)	+	+ (very weak)	+ (very weak)	–	–	–	–	–
	Argon Bulb 3000–4500 A.U.; adjacent; 16 min. in dark room	+	+	+	+	+	+	+	–	–	–	+	–
Reversal with	Frosted 60 watt Tungsten Lamp adjacent; 30 sec.*	+	+	+ (considerably weaker)	+	+	+	+	+ (slightly weaker)	+ (weaker)	+ (considerably weaker)	+	–

* Following excitation with Iron Spark as above. *Note:*—Ultra Violet: ← 4000 A. U., Visible: 4000 A. U. → 7500 A. U.

Partial Intensification in Daylight Following Complete Reversal with Electric Light

A specimen of hackmanite which had been completely reversed by exposure to electric light until nearly colorless was observed to acquire a noticeable rosy hue after a few minutes exposure to north light on a dull and cloudy day. By partially screening the mineral and again reversing the exposed area, the difference in color was made very evident. At first, this effect was attributed to a preponderance of ultra violet light over visible light occasioned by the condition of the weather, but later it was found that the color of reversed hackmanite was equally well restored by exposure to direct sunlight. The effect is then due to the normal difference in composition between electric light and daylight.

Summary of Experiments on Intensification and Reversal

The results of some of the preceding experiments, and other additional tests not specifically mentioned in the text, have been arranged for convenience in the preceding table.

Radiation Responsible for Excitation and Reversal

From inspection of these tabulated tests, we may infer that since excitation is inhibited by any filter from Corning Yellow Noviol C up to and inclusive of Corning Heat Transmitting filter No. 254, wave lengths roughly from 4800 A.U. to 39,000 A.U. are not responsible. On the other hand, ultra violet radiation down to 2250 A.U. and perhaps lower, causess intensification of color. Insofar as reversal is concerned, however, the activating radiation appears to show a peak in the visible region in wave lengths shorter than yellow, although extending to 7500 A.U., longer wave lengths up to 39,000 A.U. having no effect.

Reversible Photosensitivity in Activated Titanium Dioxide

The only other instance of a reversibly photosensitive substance which has come under the writer's notice is that of a sample of a commercial titanium oxide which possesses the property of turning to a cream color in sunlight, or under the iron spark, which tint fades to white when the material is placed in darkness for some time. A spectrographic examination kindly made by Dr. Francis C. Wood, Director of The Institute of Cancer Research of Columbia University, disclosed the presence of traces of lead and zinc, these metals having been introduced accidently in the process of manufacture.

Reversible Thermosensitivity

This related phenomenon is better known and examples are more numerous. Certain chemical substances change color on heating and reverse their acquired color on cooling, notably the allotropic mercuric iodide, HgI_2, which turns yellow on heating and becomes red again on cooling.[8] At much more elevated temperatures, the author has observed that the normal chromates of the alkaline earths of the type $RCrO_4$, change from their respective shades of greenish yellow to yellow, to orange and red shades, the original colors reappearing in reverse order on cooling. $CaCrO_4$, for instance, changes from a pure yellow to a brick red upon heating, and back again to yellow upon cooling. This is better demonstrated with electric heat, otherwise some of the chromate may be reduced to chromite, resulting upon cooling in a greenish shade instead of yellow. The extent of the color change increases with diminishing atomic number of the alkaline earth whose normal chromate is heated.

Gillespite, A Reversibly Thermosensitive Mineral

A specimen of an undetermined rose-red crystalline mineral was presented to the author some years ago through the generosity of Mr. Peter Zodac of Peekskill, New York, who stated that it had been found near Fairbanks, Alaska, by a prospector. A test for manganese was obtained, and on heating the powdered mineral, the color changed from old rose to violet blue. Upon cooling, the reverse color change occurred. This mineral was therefore reversibly thermosensitive. Although resembling piedmontite in its strong pleochroism, the mineral was quite unfamiliar to the author who submitted it to Dr. Frederick H. Pough of the Department of Mineralogy of The American Museum of Natural History, New York, for examination, and who kindly identified it as the new and very rare mineral gillespite, $FeO \cdot BaO \cdot 4SiO_2$, which has been described by Schaller[9] and Rogers.[10] It is stated to contain "Mn_2O_3" 0.14% and to darken in a closed tube when heated, assuming a deep violet color, regaining its original red color upon cooling. The manganese found was assumed to be present in the strongly chromatic manganic state, the deep red color of the mineral being attributed to this, with possibly a small quantity of ferric iron. In the abstract of the original paper, the abstractor, Dr. Edgar T. Wherry, "does not consider it probable that any manganese could occur in the manganic state in the presence of excess ferric iron, and would prefer to class this among minerals the cause of whose color is as yet undetermined." A test of this mineral under ultra violet light from the iron spark, however, gave no visible evidence of either luminescence or photosensitivity.

Mention of these reversibly thermosensitive substances is made inasmuch as it is natural to assume that the mechanism of the phenomena involved in those substances which change color reversibly under the influence of light or heat, may well have factors in common. For instance, Tool and Stair[11] have shown that the ultra violet transmission of some commercial glasses lowered through solarization can be restored by suitable heat treatment, preferably somewhat above 500°C. Visible coloration accompanying artificial solarization and decrease of transmission of the shorter visible rays, apparently disappeared completely at even lower temperatures (200° or 300°C.), this disappearance being accompanied also by visible thermoluminescence. In other words, the colors excited by short wave ultra violet light were reversed by long wave radiation (heat).

RESEARCHES OF DOELTER

Changes in the color of minerals through ultra violet, *x*-ray and Ra radiation have been extensively investigated by Doelter[12,13] who found that in general the colors were largely due to the presence of oxides of iron, chromium and manganese, and not to materials of an organic nature. The effect of radium frequently resulted in reduction, whereas ultra violet light had an oxidizing action, hence these agencies often induced opposite changes. Subsequently, he showed[14] that idiochromatic minerals, i.e., those which owe their color to a normal constituent in direct combination, are rarely affected; and concluded that the mode of combination of the substance was the dominant factor in determining color, stability decreasing from a maximum with direct union, through less stable intermediate isomorphous mixtures, to a minimum with diffuse admixture. Also, he stated[15] that many minerals contain two coloring matters, one labile and colloidal, the other stable and isomorphous with the mineral, the former being affected by Ra or ultra violet light, while the latter is not. In another paper,[16] Doelter discussed the colloidal pigments of minerals, and shows that the color of light reflected from colloidal pigment particles having diameters of the order of the wave length of light, is of greater wave length as the diameter of the particle increases. He inferred that different colors result from the same pigmentation existing in different degrees of dispersion. Other color changes in minerals under radiation, are tabulated by Doelter[17] who noted that the same species from different localities, and different samples of the same mineral from the same locality, vary in color behavior. Finally, he found[18] that minerals colored by Ra frequently exhibit changes in color following storage in the dark for several years, and those that have been afterwards decolorized by heat sometime slowly regain their color.

Generalizing from his researches, one might perhaps ascribe the behavior of hackmanite as due to the presence of labile, colloidal, diffusely admixed manganese oxide, having a particle size comparable to the wave length of light, ultra violet and visible light reversibly affecting the degree of dispersion and thus the color of the light reflected.

It should be noted, however, that in Doelter's experiments on the effect of ultra violet light on the colors of minerals, exposure for several hours was made using a specially constructed arc lamp and focusing on the specimens with a quartz lens. His researches, too, appear to have been concerned largely with the mechanism of the color changes involved, and therefore confined in the main to the study of a somewhat limited number of type species adapted to his purposes. At any rate, he did not include hackmanite in the minerals examined.

Effect of Oxidizing and Reducing Agents on the Intensified Color

Doelter[14] found also that those colors most readily developed in minerals by exposure to Ra were also as a rule the least stable. Certain minerals such as fluorite and some specimens of topaz may lose their acquired color spontaneously. In another instance, concentrated H_2O_2 was found to remove the color from the surface of fluorite and rose quartz after ten days treatment. An attempt was made therefore to determine whether the color change involved in the intensification of the color of hackmanite was due to oxidation or reduction. Following exposure to ultra violet light, color intensified areas of the mineral were treated respectively with 30% hydrogen peroxide and a strong solution of sodium hydrosulfite ($Na_2S_2O_4$). No visible change could be detected after allowing to stand for an hour, but this procedure would perhaps be more convincing if carried out on the finely powdered mineral for much longer periods, inasmuch as color intensification appears to extend well below the surface whereas the solutions used were only in superficial contact.

Spectrographic Examination of Hackmanite

As there was a strong likelihood that both the luminescent and photosensitive properties of hackmanite might be connected with the presence of the trace of manganese mentioned by Walker and Parsons, it became of interest to determine this element more precisely. Through the kindness of Dr. Lester W. Strock of the firm of Lucius Pitkin, New York, a quantitative spectrographic analysis of the reversibly photosensitive hackmanite for extraneous elements was made with the following interesting results:

Li	0.01%
Ga	0.01%
Pb	0.005%
Mn	0.001–0.002%
Be	tr.
Ba	tr.
Sr	tr.
Nd	evidence of line at 4303.61
P	tr.

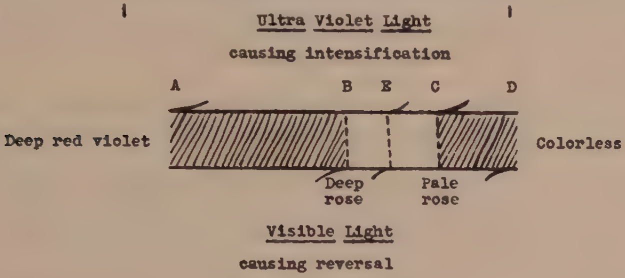
Although the concentration of manganese is lower than expected, this may be favorable to the condition postulated by Doelter in which the particle size is comparable to that of the wave lengths of light concerned. Gallium has not infrequently been reported in aluminum minerals, but the presence of some of the other unusual elements, particularly of the rare earth, may well be significant, not only in connection with the photosensitivity, but with the luminescent properties exhibited.

Conclusion

It is to be hoped that the remarkable induced reversible photosensitive behavior of the hackmanite described will be more exhaustively investigated from a more quantitative standpoint, particularly as it appears to be a new and unique property of matter in mineralogy. It would be particularly interesting to determine what, if any, relation exists between the photosensitivity and the luminescent properties in respect to the presence of manganese and the other unusual elements found. However, it may be pointed out that since the photosensitivity has been shown to be perfectly reversible and dependent on the ratio, intensity and time of the opposing activating radiations, and since their resultant effect is reflected in the intensity of the corresponding residual color, it is evident that both the partial recovery of color in darkness, following reversal, and the partial reversal in darkness, following excitation, represent (see diagram) simply two different phases (B and C) intermediate between the color extremes (A and D). It is suggested, therefore, that the cause in each case is the concomitant phosphorescence whose radiation, must also be of a compound nature. The time taken to attain equilibrium at B or C is indicative of the low intensities involved, but is to some degree compensated by the fact that the induced radiation occurs *in situ*. It may be that given sufficient time, B and C might become coincident at some intermediate point E, representative of final equilibrium.

Shaded areas represent partial reversal (AB), and intensification (CD), occurring in darkness and attributed to concomitant phosphorescence. E is the hypothetical equilibrium point.

DIAGRAM ILLUSTRATING VARIOUS PHASES OF REVERSIBLE PHOTOSENSITIVITY IN HACKMANITE FROM BANCROFT, ONTARIO



ACKNOWLEDGMENTS

Thanks are due to Van Dyk and Company, Jersey City, N. J., for the use of the quartz tube mercury vapor lamp and the "Eveready" carbon arc, to Mr. J. W. Orelup of Patent Chemicals, Jersey City, N. J., for the loan of the special filters utilized, and to Dr. H. P. Gage of the Corning Glass works, Corning, N. Y., for the calibration of the same and the gift of the water cell used.

REFERENCES

[1] Walker, T. L., and Parsons, A. L., Evanescent pink sodalite and associated minerals from Dungannon Township, Ontario: *Univ. Toronto Studies, Geol. Series*, no. **20,** p. 5, 1925.

[2] Allan, Robert, *Manual of Mineralogy*, **1834.** (Cited by Walker and Parsons. Original not consulted.)

[3] Vredenburg, E., Elaeolite and sodalite-syenites in Kishengarh State: *Records of the Geological Survey of India*, vol. **31,** p. 43, 1904.

[4] Borgström, L. H., Hackmanit, ett nytt mineral i sodalitgruppen, *Geoliska föreningen Förhandlingar, Stockholm*, vol. **23,** p. 563, 1901.

[5] Brown, W. L., Photo-phosphorescence in minerals, *Univ. Toronto Studies, Geol. Series*, no. **35,** p. 21, 1933.

[6] Barrett, Richard L., A comparison of ultra violet sources for producing fluorescence in minerals: *Am. Mineral.*, vol. **19,** p. 578, 1934.

[7] Coblentz, W. W., Dorcas, M. J. and Hughes, C. W., Radiometric measurements on the carbon arc and other light sources used in phototherapy: *Bureau of Standards, Scientific Paper* No. **539,** November 19, 1926.

[8] Mellor, J. W., *Comprehensive Treatise on Inorganic and Theoretical Chemistry*, vol. **4,** p. 903, 1923.

[9] Schaller, W. T., Gillespite, a new mineral: *Jour. Washington Academy Science*, vol. **12** (1), pp. 7–8 (Jan. 4), 1922; abstr. *Am. Mineral.*, vol. **7,** p. 147, 1922.

Schaller, W. T. The properties and associated minerals of gillespite, *Am. Mineral.*, vol. **14,** pp. 319–322, 1929.

[10] Rogers, A. F., Sandbornite, a new barium silicate mineral from Mariposa County, California: *Am. Mineral.*, vol. **17,** p. 170, 1932.

[11] Tool, A. Q., and Stair, R., The restoration of solarized ultra violet transmitting glasses by heat treatment: *Research Paper No.* **345,** *Bureau of Standards*, vol. **7,** pp. 357–374, August, 1931.

[12] Doelter, C., Über die Einwirkung von Radium- und ultravioletten Strahlen auf die Mineralfarben: *Monatshefte für Chemie und verwandte Teile anderer Wissenschafte*, vol. **30,** pp. 179–229, 1909.

[13] Doelter, C. *Das Radium und die Farben.* Einwirkung des Radiums und ultravioletter Strahlen aut organische und anorganische Stoffe sowie auf Mineralien. Steinkopf, **1910.**

[14] Doelter, C., Ueber die Stabilität der durch Radium erhaltenen Farben der Mineralien: *Centralbl. Mineral., Geologie und Pal.*, pp. 232–234, **1909.**

[15] Doelter, C., Ueber kolloide Färbemittel im Mineralreich: *Kolloid-Zeitschrift*, vol. **4,** pp. 188–189, 1909.

[16] Doelter, C., Ueber kolloide Färbemittel im Mineralreich: *Kolloid-Zeitschrift*, vol. **26,** pp. 23–27, 1920.

[17] Doelter, C., Neue Untersuchungen über die Farbenveränderungen von Mineralien durch Strahlungen: *Sitzungsber. Akad. Wissenschaften in Wien*, Abteilung I, vol. **129,** pp. 399–430, 1920.

[18] Doelter, C., Beobachtungen über Verfärbung von Mineralen durch Bestrahlung: *Mineral. und Petro. Mitt.*, vol. **38,** pp. 456–463, 1925.

ORIENTED INCLUSIONS OF TOURMALINE IN MUSCOVITE*

CLIFFORD FRONDEL, *Massachusetts Institute of Technology, Cambridge, Mass.*

CONTENTS

Summary 777
Introduction 779
Habit and Flattening of Prismatic Inclusions 780
    Polar Growth of Tourmaline 782
Orientation of Prismatic Inclusions 782
    Inclusions Flattened on $(11\bar{2}0)$ 782
    Inclusions Flattened on $(10\bar{1}0)$ 788
Habit and Orientation of Inclusions Flattened on (0001) 792
Discussion 796
Associated Minerals 798

SUMMARY

The paper presents a study of the habit, plane of flattening, and orientation to the mica of tourmaline crystals enclosed between the basal cleavages of muscovite. The study is largely statistical, and includes an analysis of 710 examples from Gilsum, N. H., and of 109 examples from New York City.

The following forms and planes of flattening were identified:

	Gilsum, N. H.				New York City			
Plane of Flattening	$(11\bar{2}0)$	$(10\bar{1}0)$	(0001)	Other	$(11\bar{2}0)$	$(10\bar{1}0)$	(0001)	Other
Per cent of Total	59.9	12.3	16.7	11.1	45.9	23.9	22.9	7.2
Observed Forms	ore_1r_1	or_1r	a		or_1r	or_1r	amm_1	

Although the tourmaline inclusions did not appear on casual examination to be oriented in relation to the muscovite, tendencies for arrangement in preferred crystallographic orientations were recognized on statistical study. The 18 well-defined and 8 ill-defined separate orientations established included approximately one-half of the total number of inclusions observed from each locality. The remaining inclusions are not distributed at random, but occupy regions, between the clearly defined positions of orientation, in which the statistical population is presumably insufficient to define exact positions of orientation. The number of different orientations that can be recognized appears to depend only on the extent of statistical investigation.

---

* A thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts in the Faculty of Pure Science, Columbia University, May, 1936.

The observed positions of orientation are found to correspond to calculated positions in which a direction of relatively low index in the plane of flattening of the tourmaline coincides with a direction of relatively low index in (001) of the muscovite. The frequency of orientation roughly increases with the increasing rationality of the coinciding directions. The observed orientations are as follows:

Locality	Plane of Flattening	Reference Direction	Coincidences of Reference Direction on Muscovite (001) with Per Cent of Total, at Each Position									
Gilsum	$(11\bar{2}0)$	*c*	110 $1\bar{1}0$	320 $3\bar{2}0$	130 $1\bar{3}0$	100	340 $3\bar{4}0$	010	120 $1\bar{2}0$	230 $2\bar{3}0$	310 $3\bar{1}0$	210 $2\bar{1}0$
			16.6	4.5	4.1	2.7	2.4	2.1	1.8	1.8	1.7	1.4
	$(11\bar{2}0)$	$10\bar{1}1$	110 $1\bar{1}0$	100								
			?	?								
	$(11\bar{2}0)$	$\bar{1}011$	110 $1\bar{1}0$	010								
			?	?								
New York City	$(11\bar{2}0)$	*c*	110 $1\bar{1}0$	010	320 $3\bar{2}0$	130 $1\bar{3}0$	100	310 $3\bar{1}0$				
			9.2	3.7	3.7	2.7	1.8	1.8				
Gilsum	$(10\bar{1}0)$	*c*	110 $1\bar{1}0$	130 $1\bar{3}0$	010	320 $3\bar{2}0$	100	310 $3\bar{1}0$	340 $3\bar{4}0$			
			1.1	.42	.28	.29	?	?	?			
New York City	$(10\bar{1}0)$	*c*	010	110 $1\bar{1}0$	100							
			3.7	2.7	1.8							
			Percussion Figure	Pressure Figure	19° posit. (Table 8)	11° posit. (Table 8)	5° posit. (Table 8)					
Gilsum	(0001)	$11\bar{2}0$	7.3	2.6	1.6	?	?					
New York	(0001)	$11\bar{2}0$	10.6	3.5	2.9	?						

It is suggested that, in general, orientation is not restricted to specific, limiting conditions of crystallographic coincidence, but that a degree of frequency is associated with each of an infinitude of orientations between over- or inter-growing and substrate crystals of any two species.

The rate of growth of tourmaline along its polar *c* axis is noted to be greater in the antilogous direction than in the analogous direction.

Introduction

Although tourmaline crystals often occur as flattened inclusions between the basal laminae of muscovite, the orientation of the crystals with respect to the muscovite has seldom been remarked. The recognized instances of orientation, described by Volger,[1] Linck[2] and Mügge[3] from a few observations, fall into three types: crystals flattened on $(11\bar{2}0)$ with *c* parallel to a ray of the percussion figure or the pressure figure of the mica, and crystals flattened on (0001) with the faces of $(11\bar{2}0)$ parallel to the rays of the pressure figure. The minute needle-like inclusions characteristic of phlogopite, oriented parallel to the pressure or percussion figures and causing asterism, have been thought to be tourmaline but have since[4] been identified as rutile.

In the present study, the habit, plane of flattening and orientation was determined of 710 tourmaline crystals included in pale yellow-brown muscovite from a pegmatite at Gilsum, N. H., and of 109 crystals included in brown muscovite from a pegmatitic zone in Manhattan schist at 172nd Street and Fort Washington Avenue, New York City. The pegmatites of the Gilsum area have been described by Megathlin.[5]

The majority of the inclusions were prismatic in habit, and ranged between 0.5–5 mm. in length, 0.1–1 mm. in width and 0.005–0.5 mm. in thickness. One doubly terminated crystal was noted that had the remarkable dimensions of 920×0.2×0.01 mm. Some of the crystals were so thin as to give interference colors in ordinary light. It was observed that the flattening—that is, the relation of length and breadth to thickness—of the prismatic inclusions was greater in small crystals than in large crystals. The Gilsum crystals ranged in color from pure black in the thicker, opaque individuals to various shades of yellow-brown and smoke-gray in the thinner, transparent, individuals. The New York City crystals ranged in color from a brownish black to a light yellow-brown.

[1] Volger, O., *Jahresber. Wetterauischen Ges., Hanau,* **1861–63,** p. 67.

[2] Linck, G., *Jenaische Zeits. Naturwiss.*, vol. **33,** pp. 350–351, 1899.

[3] Mügge, O., *Neues Jahrb., Beil.-Bd.* **16,** p. 388, 1903.

[4] Pogue, J. E., *Proc. U. S. Nat. Mus.*, vol. **39,** pp. 572–576, 1911.

[5] Megathlin, G. R., *Econ. Geol.*, vol. **24,** pp. 163–181, 1929.

The angle χ, used to denote the angles of the percussion figure opposite to 010 and bisected by the optic plane, and which mark the actual position of the subsidiary, 110 and $1\bar{1}0$, rays of the figure, had a minimum value of 50° 45′ for the Gilsum muscovite, and of 52° 18′ for the New York City muscovite. Walker[6] obtained minimum values of χ ranging from 52° 53′ for muscovite from Murray Bay, Quebec, to 55° 57′ for muscovite from Utö, Sweden.

The great majority of the inclusions are either flattened in the prism zone and elongated parallel to c, or are flattened on (0001). A small proportion of the inclusions appeared to be flattened on planes inclined to c. No tendency for orientation of the inclusions to the muscovite was apparent on a cursory examination of the specimens.

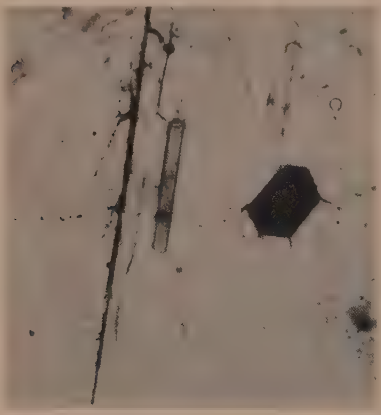


FIG. 1. The prismatic tourmaline inclusion is flattened on $(11\bar{2}0)$ and is oriented with c parallel to 010 of the muscovite. The 010 ray of a percussion figure can be seen in the photograph. The hexagonal inclusion is flattened on (0001) and is bounded laterally by $(11\bar{2}0)$; the crystal is oriented with the faces of $(11\bar{2}0)$ parallel to the rays of the pressure figure. Gilsum, N. H. ×30.

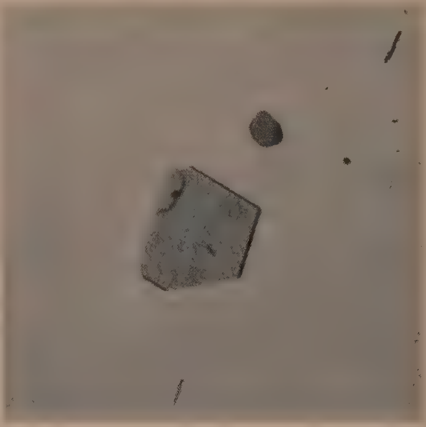


FIG. 2. The prismatic tourmaline inclusion is flattened on $(11\bar{2}0)$; the twelve-sided inclusion is flattened on (0001) and is bounded laterally by $(11\bar{2}0)$, $(10\bar{1}0)$ and $(01\bar{1}0)$. New York City. ×30.

HABIT AND FLATTENING OF PRISMATIC INCLUSIONS

Inclusions flattened in the prism zone are shown in Figs. 1 and 2. The crystals are characteristically terminated by a pair of faces at each extremity of c; additional faces may be present but are minute in size.

[6] Walker, T. L., *Am. Jour. Sci.*, ser. 4, vol. **2**, p. 5, 1896.

TABLE 1
HABIT AND FLATTENING OF PRISMATIC INCLUSIONS. GILSUM, N. H., AND NEW YORK CITY

Locality: Gilsum, N.H.	Number of Crystals Observed	Plane of Flattening	Measured Angles (Average)				Calculated Angles and Corresponding Forms			
			Pole X		Pole X′		Antilogous Pole		Analogous Pole	
			A	B	M	N	A	B	M	N
Habit I	96	$(11\bar{2}0)$	44°16′	62°48′	75°8′	62°49′	44°3′ $o(02\bar{2}1)$	62°40′ o'/o''	75°30′ r_1'/r_1''	62°40′ $r_1(01\bar{1}\bar{1})$
Habit II	25	$(11\bar{2}0)$	44°27′	63°9′	75°15′	62°55′	44°3′ $o(02\bar{2}1)$	62°40′ $r(10\bar{1}1)$	75°30′ $e_1(10\bar{1}\bar{2})$	62°40′ $r_1(01\bar{1}\bar{1})$
Habit III	12	$(11\bar{2}0)$	44°30′	62°26′	75°34′	62°59′	44°3′ $o(02\bar{2}1)$	62°40′ $r(10\bar{1}1)$	75°30′ r_1'/r_1''	62°40′ $r_1(01\bar{1}\bar{1})$
Habit IV	28	$(11\bar{2}0)$	75°54′	62°39′	75°27′	63°0′	75°30′ r'/r''	62°40′ $r(10\bar{1}1)$	75°30′ r_1'/r_1''	62°40′ $r_1(01\bar{1}\bar{1})$
Habit V	22	$(10\bar{1}0)$	48°40′	49°4′	66°49′	66°8′	48°9′ $o(02\bar{2}1)$	48°9′ o''	65°53′ $r_1(01\bar{1}\bar{1})$	65°53′ r_1''
Habit VI	11	$(10\bar{1}0)$	66°36′	65°20′	65°42′	65°30′	65°53′ $r(10\bar{1}1)$	65°53′ r''	65°53′ $r_1(01\bar{1}\bar{1})$	65°53′ r_1''

Inclusions otherwise flattened: 30 Inclusions unidentified as to flattening: 367

New York City										
Habit I	28	$(11\bar{2}0)$	44°17′	63°8′	74°56′	62°32′	44°3′ $o(02\bar{2}1)$	62°40′ o'/o''	75°30′ r_1'/r_1''	62°40′ $r_1(01\bar{1}\bar{1})$
Habit II	16	$(11\bar{2}0)$	75°19′	62°50′	75°27′	62°18′	75°30′ r'/r''	62°40′ $r(10\bar{1}1)$	75°30′ r_1'/r_1''	62°40′ $r_1(01\bar{1}\bar{1})$
Habit III	6	$(10\bar{1}0)$	48°36′	48°23′	66°37′	66°21′	48°9′ $o(02\bar{2}1)$	48°9′ o''	65°53′ $r_1(01\bar{1}\bar{1})$	65°53′ r_1''
Habit IV	17	$(10\bar{1}0)$	65°44′	66°9′	66°17′	65°21′	65°53′ $r(10\bar{1}1)$	65°53′ r''	65°53′ $r_1(01\bar{1}\bar{1})$	65°53′ r_1''

Inclusions otherwise flattened: 7 Inclusions unidentified as to flattening: 10

The exact plane of flattening of the inclusions was determined by first measuring the angles made by the terminating forms with *c*, measured in the plane of flattening. A tabulation of the measurements showed that most of the inclusions fell into habit groups characterized by a close similarity of terminal angles. By trial, assuming various planes of flattening in the prism zone, rational indices for the terminal faces were obtained for some of the habit groups in the case of $(11\bar{2}0)$, and for the remaining habit groups in the case of $(10\bar{1}0)$. This data is tabulated for the two occurrences in Table 1. The terminal angles of the remaining crystals differed from those of all of the habit groups and varied among themselves; some of these crystals were flattened in the prism zone on unidentified planes, but most of them appeared to be flattened on planes inclined to *c*. A proportion of the inclusions from both localities had rounded or irregular terminations and their plane of flattening could not be identified.

In identifying the forms from the measurements it is important to note whether the terminating faces are perpendicular to the plane of flattening or are inclined to it, since faces that bevel or truncate a given termination make the same plane angle on *c*. The form *o* $(02\bar{2}1)$ occurred at one end of the polar *c* axis only and, in accordance with the general rule, this end was taken as the antilogous pole. The habit differs in forms present, their combinations and their relative frequencies, both with the plane of flattening and with the locality.

Polar growth of tourmaline. Many of the crystals from both localities showed internal zones of growth. The spacing of the growth zones varies at opposite ends of the polar axis, being invariably wider at the antilogous pole, even in crystals terminated at opposite poles by geometrically like forms. This relation indicates that the rate of growth is greater in the antilogous direction of the polar axis than in the opposite, analogous, direction. The rate of solution in tourmaline, on the other hand, is greater in the analogous direction.[7] Other substances[8] show a similar variability in rate of growth at opposite ends of a polar axis.

ORIENTATION OF PRISMATIC INCLUSIONS

Inclusions Flattened on $(11\bar{2}0)$. The orientation of the prismatic inclusions to the muscovite can be defined by stating the position of a direction in the plane of flattening of the inclusions relative to a direction in (001) of the muscovite. The observed positions of the inclusions flattened on $(11\bar{2}0)$, obtained by direct measurement of the angle made by the *c* direction of tourmaline to 010 of muscovite are graphed to the nearest degree in Tables 2 (Gilsum) and 3 (New York City). The positive and negative inclinations about 010, the plane of symmetry, are not distinguished.

---

[7] Frondel, C., *Am. Mineral.*, vol. **20**, pp. 855–856, 1935.

[8] Bentivoglio, M., *Proc. Royal Soc. London*, vol. **115A**, pp. 81–83, 1927.

TABLE 2. OBSERVED ORIENTATIONS OF TOURMALINE (11$\bar{2}$0) UPON MUSCOVITE (001).
GILSUM, N. H.
Reference directions: $c \wedge 010$

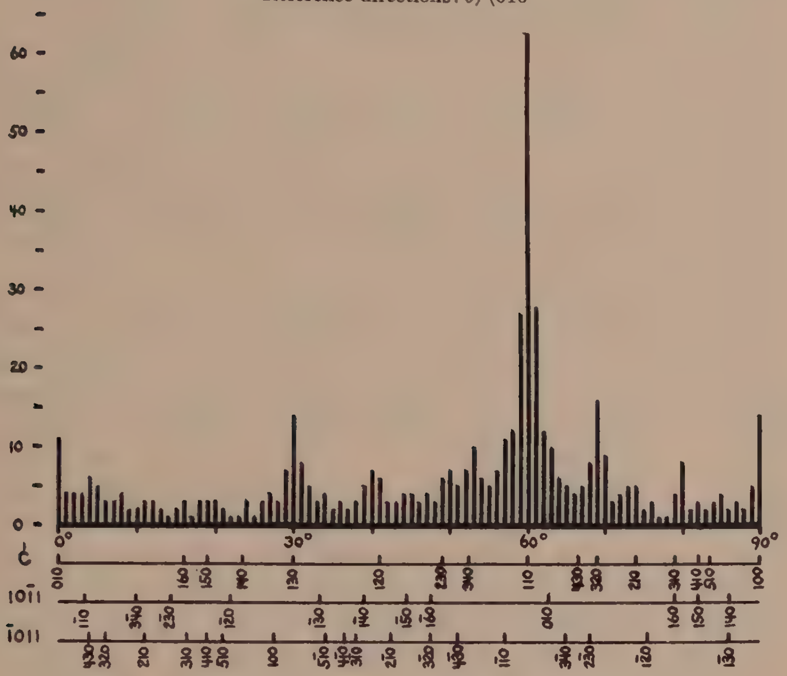


TABLE 3. OBSERVED ORIENTATIONS OF TOURMALINE (11$\bar{2}$0) UPON MUSCOVITE (001).
NEW YORK CITY
Reference directions: $c \wedge 010$

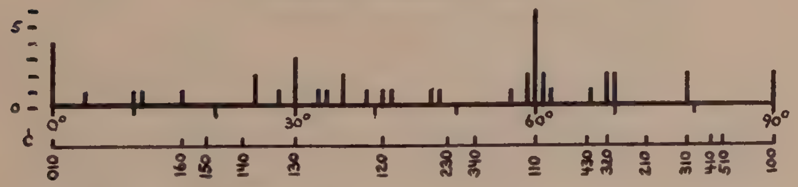


Table 2 (Gilsum), which comprises 528 inclusions,[9] shows maxima at particular values of $c \wedge 010$, of which those at 0°, 30°, 40°, 50°, 53°, 60°,

---

[9] This graph is composite, and contains a proportion of inclusions flattened on (10$\bar{1}$0) and other, unidentified, planes. The majority of the inclusions from Gilsum had rounded or irregular terminations and the plane of flattening could not be determined by the method

69°, 74°, 80° and 90° can be considered as well-defined. These maxima represent preferred orientations of the inclusions in the contact surface tourmaline $(11\bar{2}0)$–(001) muscovite.

In Table 4 the calculated coincidences[10] for *c* and a few other directions of relatively low indices in tourmaline $(11\bar{2}0)$ and muscovite (001) are tabulated for values of $c\wedge 010$. The table cites the successive positions in which crystallographic directions in the plane of flattening of the tourmaline coincide with crystallographic directions in (001) of the muscovite as the tourmaline crystal is rotated through 90° on the contact surface. For instance, tourmaline $10\bar{1}4$ coincides with muscovite $4\bar{1}0$ when *c* is inclined 1° 09′ to 010, and with muscovite $7\bar{2}0$ when *c* is inclined 2° 00′ to 010. The details of coincidence within the table could be extended indefinitely by including directions of higher indices in the two minerals. Similar coincidence tables can be calculated for any plane of contact between two species of crystals.

By reference to the table of calculated coincidences, it is found that the various observed positions of orientation mark major calculated coincidences in the contact surface. All appear to correspond to calculated coincidences made by *c* with directions of relatively low indices in muscovite (001), as follows: 010, 130, 120, 230, 340, 110, 320, 210, 310 and 100. These positions fall into a N_3 complication series, with an extra term at 3/4, but the percentages of orientation at each position (see Summary) have no analogous relationship. It should be understood that the fact that the most rational coincidences are made by *c* is not a consequence of using *c* as a reference direction for measurement; the same coincidences would have been found if any other direction in tourmaline $(11\bar{2}0)$ had been chosen as the basis of measurement.

Considerations of crystallographic coincidence made by tourmaline *c* upon muscovite (001), therefore, have influenced the crystallization of the tourmaline to a greater extent than any of the innumerable other coincidences in the respective contact planes. As will be seen, however, there is evidence that other coincidences in the contact surface, between directions of higher indices, are working in conjunction with *c* to control orientation at the various observed positions. Also,

---

described, although the position of *c* could be identified in every instance. In preparing this graph, all observations were included except those of crystals previously identified by measurement (Table 1) as being flattened on some plane other than $(11\bar{2}0)$. Assuming that the proportion of crystals flattened on $(11\bar{2}0)$ out of the total number of prismatic inclusions noted is the same as that of crystals whose plane of flattening was determinable, the composite graph will contain 80% of $(11\bar{2}0)$ crystals. Separate plotting of the crystals definitely identified as being flattened on $(11\bar{2}0)$ gave a graph that closely paralleled that of Table 2.

[10] Tourmaline $c=.44767$; muscovite $a:b:.=57735:1$.

TABLE 4

CALCULATED PRINCIPAL COINCIDENCES BETWEEN MUSCOVITE (001) AND TOURMALINE (11$\bar{2}$0)
Divergence from exact coincidence as given. Observed coincidences indicated by asterisk.

Tourm. $c\wedge$ muscov. 010	10$\bar{1}$4 $\bar{1}$01$\bar{4}$		$\bar{1}$014 10$\bar{1}\bar{4}$		10$\bar{1}$2 $\bar{1}$01$\bar{2}$		$\bar{1}$012 10$\bar{1}\bar{2}$		10$\bar{1}$1 $\bar{1}$01$\bar{1}$		$\bar{1}$011 10$\bar{1}\bar{1}$		20$\bar{2}$1 $\bar{2}$02$\bar{1}$		$\bar{2}$021 20$\bar{2}\bar{1}$		40$\bar{4}$1 $\bar{4}$04$\bar{1}$		$\bar{4}$041 40$\bar{4}\bar{1}$		000$\bar{1}$ 0001		c	
* 0																					100	0′	010	0′
1	4$\bar{1}$0	9′	510	−13′			730	−24′			760	0′			470	−20′			270	−28′				
2	7$\bar{2}$0	0′	610	−8′	2$\bar{1}$0	24′	520	−30′			650	−26′			350	3′	1$\bar{4}$0	−23′						
? 3			710	−21′					1$\bar{1}$0	20′	540	−27′	1$\bar{2}$0	−9′										
4	3$\bar{1}$0	28′			7$\bar{4}$0	15′	310	−24′			430	−5′							130	12′				
5					5$\bar{3}$0	24′	720	8′			750	−5′			230	4′					7$\bar{1}$0	17′		
6	5$\bar{2}$0	22′					410	17′			320	17′									6$\bar{1}$0	30′		
7	7$\bar{3}$0	28′	100	22′	3$\bar{2}$0	27′			5$\bar{6}$0	−23′			3$\bar{7}$0	−28′	570	0′	1$\bar{5}$0	18′			5$\bar{1}$0	25′		
8					7$\bar{5}$0	5′	510	−5′	4$\bar{5}$0	−29′	530	14′			340	22′					4$\bar{1}$0	−13′		
9	2$\bar{1}$0	16′			4$\bar{3}$0	5′	610	0′			740	5′	2$\bar{5}$0	−20′					250	−5′	7$\bar{2}$0	−22′		
10					5$\bar{4}$0	−17′	710	−13′	3$\bar{4}$0	−15′					450	8′	1$\bar{6}$0	18′						
11	7$\bar{4}$0	7′			6$\bar{5}$0	−16′					210	14′			560	14′			370	−13′	3$\bar{1}$0	6′		
12	5$\bar{3}$0	16′	7$\bar{1}$0	−5′	7$\bar{6}$0	10′			5$\bar{7}$0	23′					670	−1′	1$\bar{7}$0	6′						
13			6$\bar{1}$0	8′							730	26′									5$\bar{2}$0	0′		
14	3$\bar{2}$0	19′	5$\bar{1}$0	3′			100	30′	2$\bar{3}$0	27′	520	20′	1$\bar{3}$0	−3′							7$\bar{3}$0	6′	170	−6′
15	7$\bar{5}$0	−3′																	120	6′				
16	4$\bar{3}$0	−3′	4$\bar{1}$0	25′	1$\bar{1}$0	30′					310	26′			110	−3′					2$\bar{1}$0	−6′	160	6′
17	5$\bar{4}$0	−25′	7$\bar{2}$0	16′					3$\bar{5}$0	26′														
18	6$\bar{5}$0	−24′	3$\bar{1}$0	−16′					4$\bar{7}$0	3′	720	−2′	2$\bar{7}$0	17′							7$\bar{4}$0	−15′		
19	7$\bar{6}$0	2′			6$\bar{7}$0	−28′	7$\bar{1}$0	−13′			410	7′							470	−5′	5$\bar{3}$0	−6′	150	6′
20			5$\bar{2}$0	−22′	5$\bar{6}$0	−13′	6$\bar{1}$0	0′							650	11′			350	18′				
21			7$\bar{3}$0	−16′	4$\bar{5}$0	−19′	5$\bar{1}$0	−5′			510	−15′	1$\bar{4}$0	22′	540	10′					3$\bar{2}$0	−3′		
22									1$\bar{2}$0	14′	610	−10′									7$\bar{5}$0	−25′		
23	1$\bar{1}$0	22′	2$\bar{1}$0	−28′	3$\bar{4}$0	−5′	4$\bar{1}$0	17′			710	−23′			430	−28′			230	19′	4$\bar{3}$0	−25′	140	25′
24					5$\bar{7}$0	−27′	7$\bar{2}$0	8′							750	−28′								
25							3$\bar{1}$0	−24′					1$\bar{5}$0	3′	320	−6′			570	15′	5$\bar{4}$0	13′		
26			7$\bar{4}$0	23′	2$\bar{3}$0	−23′			3$\bar{7}$0	−5′							010	−12′			6$\bar{5}$0	14′	270	20′
? 27	5$\bar{6}$0	−21′					5$\bar{2}$0	−30′			100	20′			530	−9′			340	−23′				
28	4$\bar{5}$0	−27′	3$\bar{2}$0	−25′			7$\bar{3}$0	−24′	2$\bar{5}$0	3′			1$\bar{6}$0	3′	740	−18′			450	23′				
29					3$\bar{5}$0	−24′													560	29′				

TABLE 4.—(*Continued*)

CALCULATED PRINCIPAL COINCIDENCES BETWEEN MUSCOVITE (001) AND TOURMALINE (11$\bar{2}$0)
Divergence from exact coincidence as given. Observed coincidences indicated by asterisk.

Tourm. c∧ muscov. 010	$10\bar{1}4$ $\bar{1}01\bar{4}$		$\bar{1}014$ $10\bar{1}\bar{4}$		$10\bar{1}2$ $\bar{1}01\bar{2}$		$10\bar{1}2$ $\bar{1}01\bar{2}$		$10\bar{1}1$ $\bar{1}01\bar{1}$		$\bar{1}011$ $10\bar{1}\bar{1}$		$20\bar{2}1$ $\bar{2}02\bar{1}$		$\bar{2}021$ $20\bar{2}\bar{1}$		$40\bar{4}1$ $\bar{4}04\bar{1}$		$\bar{4}041$ $40\bar{4}\bar{1}$		$000\bar{1}$ 0001		c	
* 30	$3\bar{4}0$	−13′	$7\bar{5}0$	13′									$1\bar{7}0$	−9′	210	−9′			670	14′	$1\bar{1}0$	0′	130	0′
31			$4\bar{3}0$	13′	$4\bar{7}0$	13′	$2\bar{1}0$	24′																
32	$5\bar{7}0$	25′	$5\bar{4}0$	−9′							$7\bar{1}0$	−3′			730	3′								
33			$6\bar{5}0$	−8′			$7\bar{4}0$	15′	$1\bar{3}0$	20′	$6\bar{1}0$	10′			520	−3′								
34	$2\bar{3}0$	29′	$7\bar{6}0$	18′			$5\bar{3}0$	24′			$5\bar{1}0$	5′							110	12′	$6\bar{7}0$	2′		
35					$1\bar{2}0$	24′									310	3′					$5\bar{6}0$	17′	250	−17′
36							$3\bar{2}0$	27′	$2\bar{7}0$	−20′	$4\bar{1}0$	27′									$4\bar{5}0$	11′		
37	$3\bar{5}0$	28′	$1\bar{1}0$	−22′			$7\bar{5}0$	5′			$7\bar{2}0$	18′			720	−25′							370	−25′
38	$4\bar{7}0$	5′					$4\bar{3}0$	5′			$3\bar{1}0$	−14′			410	−16′			650	26′	$3\bar{4}0$	25′		
39					$3\bar{7}0$	5′	$5\bar{4}0$	−17′	$1\bar{4}0$	−15′					510	22′			540	25′	$5\bar{7}0$	3′		
40							$6\bar{5}0$	−16′			$5\bar{2}0$	−20′			610	27′	170	−18′						
* 41			$6\bar{7}0$	−20′	$2\bar{5}0$	13′	$7\bar{6}0$	10′			$7\bar{3}0$	−14′			710	14′			430	−13′	$2\bar{3}0$	7′	120	−6′
42	$1\bar{2}0$	16′	$5\bar{6}0$	−5′													160	−6′	750	−13′				
43			$4\bar{5}0$	−11′							$2\bar{1}0$	−26′							320	9′				
44									$1\bar{5}0$	26′			010	−3′							$3\bar{5}0$	6′		
45			$3\bar{4}0$	3′	$1\bar{3}0$	−30′	$1\bar{1}0$	30′			$7\bar{4}0$	−35′					150	−6′	530	6′	$4\bar{7}0$	−17′	470	−17′
46	$3\bar{7}0$	−3′	$5\bar{7}0$	−19′							$5\bar{3}0$	−26′			100	3′			740	−3′			350	6′
47									$1\bar{6}0$	26′														
48	$2\bar{5}0$	5′	$2\bar{3}0$	−15′			$6\bar{7}0$	−28′			$3\bar{2}0$	−23′							210	6′				
* 49					$2\bar{7}0$	−10′	$5\bar{6}0$	−13′	$1\bar{7}0$	14′							140	13′			$1\bar{2}0$	−6′	230	7′
50							$4\bar{5}0$	−19′			$7\bar{5}0$	15′							730	18′				
51			$3\bar{5}0$	−16′							$4\bar{3}0$	15′			$6\bar{1}0$	−27′			520	12′			570	3′
* 52					$1\bar{4}0$	−5′	$3\bar{4}0$	−5′			$5\bar{4}0$	−7′					270	8′					340	25′
53	$1\bar{3}0$	22′	$4\bar{7}0$	21′			$5\bar{7}0$	−27′			$6\bar{5}0$	−6′			$5\bar{1}0$	28′			310	18′	$3\bar{7}0$	−25′		
54											$7\bar{6}0$	20′			$4\bar{1}0$	−10′							450	11′
55							$2\bar{3}0$	−23′							$7\bar{2}0$	−19′			720	−10′	$2\bar{5}0$	−17′	560	17′
56	$2\bar{7}0$	−18′	$1\bar{2}0$	−28′	$1\bar{5}0$	−24′											130	−12′	410	−1′			670	2′
? 57											$1\bar{1}0$	−20′			$3\bar{1}0$	9′								
58							$3\bar{5}0$	−24′					170	−3′					510	−23′				
59	$1\bar{4}0$	−13′			$1\bar{6}0$	−24′									$5\bar{2}0$	3′			610	−18′				

Table 4.—(*Continued*)

Calculated Principal Coincidences between Muscovite (001) and Tourmaline (11$\bar{2}$0)
Divergence from exact coincidence as given. Observed coincidences indicated by asterisk.

Tourm. $c\wedge$ muscov. 010	$10\bar{1}4$ $\bar{1}01\bar{4}$	$\bar{1}014$ $10\bar{1}\bar{4}$	$10\bar{1}2$ $\bar{1}01\bar{2}$	$\bar{1}012$ $10\bar{1}\bar{2}$	$10\bar{1}1$ $\bar{1}01\bar{1}$	$\bar{1}011$ $10\bar{1}\bar{1}$	$20\bar{2}1$ $\bar{2}02\bar{1}$	$\bar{2}021$ $20\bar{2}\bar{1}$	$40\bar{4}1$ $\bar{4}04\bar{1}$	$\bar{4}041$ $40\bar{4}\bar{1}$	$000\bar{1}$ 0001	c
* 60				$4\bar{7}0$ 13′			160 9′	$7\bar{3}0$ 9′			$1\bar{3}0$ 0′	110 0′
61		$3\bar{7}0$ 13′				$6\bar{7}0$ −18′			250 −29′			
62			170 24′			$5\bar{6}0$ −3′		$2\bar{1}0$ −3′	370 23′			
* 63		$2\bar{5}0$ 21′			010 −20′	$4\bar{5}0$ −9′	150 9′					
64	$1\bar{5}0$ 28′			$1\bar{2}0$ 24′				$7\bar{4}0$ −12′		100 12′	$2\bar{7}0$ 20′	650 14′
65						$3\bar{4}0$ 5′		$5\bar{3}0$ −3′				540 13′
66						$5\bar{7}0$ −17′						
67	$1\bar{6}0$ 28′	$1\bar{3}0$ −22′					140 28′	$3\bar{2}0$ 0′	120 −18′		$1\bar{4}0$ 25′	430 −25′
68				$3\bar{7}0$ 5′		$2\bar{3}0$ −13′		$7\bar{5}0$ −22′				750 −25′
* 69	170 16′							$4\bar{3}0$ −22′		$7\bar{1}0$ 5′		320 −3′
70				$2\bar{5}0$ 13′			270 23′			$6\bar{1}0$ 18′		
71		$2\bar{7}0$ −2′				$3\bar{5}0$ −14′		$5\bar{4}0$ 16′	470 −29′	$5\bar{1}0$ 13′	$1\bar{5}0$ 6′	530 −6′
72								$6\bar{5}0$ 17′	350 −6′	$4\bar{1}0$ −25′		740 −15′
73						$4\bar{7}0$ 23′						
* 74		$1\bar{4}0$ 3′		$1\bar{3}0$ −30′			130 3′			$7\bar{2}0$ 26′	$1\bar{6}0$ 6′	210 −6′
75									230 −5′	$3\bar{1}0$		
76			010 −30′			$1\bar{2}0$ −26′		$1\bar{1}0$ 3′			$1\bar{7}0$ −6′	730 6′
77					170 −26′				570 −9′	$5\bar{2}0$ −12′		520 0′
78		$1\bar{5}0$ −16′		$2\bar{7}0$ −10′					340 13′	$7\bar{3}0$ −6′		
* 79					160 −14′		250 −14′					310 6′
80								$6\bar{7}0$ 5′	450 −1′	$2\bar{1}0$ −18′		
81		$1\bar{6}0$ −16′		$1\bar{4}0$ −5′		$3\bar{7}0$ 15′	370 −22′	$5\bar{6}0$ 20′	560 5′			720 −22′
82					150 −14′			$4\bar{5}0$ 14′	670 −10′	$7\bar{4}0$ −27′		410 −13′
83	010 −22′	$1\bar{7}0$ −28′				$2\bar{5}0$ 23′				$5\bar{3}0$ −18′		510 25′
84								$3\bar{4}0$ 28′				610 30′
85				$1\bar{5}0$ −24′			120 −3′	$5\bar{7}0$ 6′		$3\bar{2}0$ −15′		710 17′
86					140 5′				110 −12′			
87						$1\bar{3}0$ −20′		$2\bar{3}0$ 10′		$7\bar{5}0$ 23′		
88				$1\bar{6}0$ −24′						$4\bar{3}0$ 23′		
89			170 24′		270 0′		470 −14′		760 28′	$5\bar{4}0$ 1′		
* 90							350 9′	$3\bar{5}0$ 9′	650 2′	$6\bar{5}0$ 2′	010 0′	100 0′

there is no reason to suppose that lower coincidences in the contact surface are not acting independently at other values of $c\wedge 010$, to control orientation. The observations may not be sufficiently numerous, as a whole, to define such positions in the graphs. As a matter of fact, evidence can be found of controlling effect of coincidences made by tourmaline $10\bar{1}1$ and $\bar{1}011$. The shoulders at the 57° and 63° positions on the 60° maximum are too well-defined to be caused by errors of measurement, and seem to correspond to major coincidences made by $\bar{1}011$ with $1\bar{1}0$ and of $10\bar{1}1$ with 010. An ill-defined maximum at 4° also apparently corresponds to a coincidence made by $10\bar{1}1$ with 110, and an ill-defined maximum at 27° apparently corresponds to a coincidence made by $\bar{1}011$ with 100. The coincidences made by $\bar{1}011$, $10\bar{1}1$ and c are indicated on the graph.

The broadness of the 60° maximum may also have been caused in other ways. Possibly the nearly oriented inclusions were exactly oriented in their nuclear stage of development, but subsequently diverged from this position due to disturbances of growth. On the other hand, it may be that the inclusions are exactly oriented on minute blocks of the muscovite crystal that are in sub-parallel position with the whole crystal, or vice versa. Rayleigh,[11] however, has shown that the (001) surfaces of some muscovite crystals are uniform in macrostructure to an extraordinarily high degree.

The observed positions of orientation of the inclusions flattened on $(11\bar{2}0)$ from the New York City occurrence are graphed for the measured values of $c\wedge 010$ in Table 3. Only those crystals known (Table 1) to be flattened on $(11\bar{2}0)$ are included. As with the Gilsum occurrence, definite maxima are present which identify positions of preferred orientation of the inclusions. The maxima correspond in angular position to calculated coincidences (Table 4) made by c with 010, 130, 110, 320, 310 and 100. The relative frequency of the various orientations, however, is slightly different from that of the Gilsum occurrence. Such a variation may be caused by a difference in lattice dimensions arising from a difference in composition, or they may reflect different temperatures of formation if significant relative changes in the dimensions of the two structures take place with changes in temperature.

Inclusions flattened on $(\bar{1}010)$. The observed positions of orientation of the inclusions definitely identified (Table 1) as being flattened on $(10\bar{1}0)$ are graphed for the measured values of $c\wedge 010$ in Tables 5 (Gilsum) and 6 (New York City). The calculated coincidences for c and a few other directions of relatively low indices in tourmaline $(10\bar{1}0)$ and muscovite (001) are tabulated for values of $c\wedge 010$ in Table 7.

---

[11] Rayleigh, *Phil. Mag.*, vol. **19**, pp. 96–99, 1910.

TABLE 7

CALCULATED PRINCIPAL COINCIDENCES BETWEEN MUSCOVITE (001) AND TOURMALINE (10$\bar{1}$0)
Divergence from exact coincidence as given. Observed coincidences indicated by asterisk.

Tourm. $c\wedge$ muscov. 010	$\bar{1}2\bar{1}8$ $1\bar{2}1\bar{8}$	$1\bar{2}18$ $\bar{1}2\bar{1}\bar{8}$	$\bar{1}2\bar{1}4$ $1\bar{2}1\bar{4}$	$1\bar{2}14$ $\bar{1}2\bar{1}\bar{4}$	$\bar{1}2\bar{1}2$ $1\bar{2}1\bar{2}$	$1\bar{2}12$ $\bar{1}2\bar{1}\bar{2}$	$\bar{1}2\bar{1}1$ $1\bar{2}1\bar{1}$	$1\bar{2}11$ $\bar{1}2\bar{1}\bar{1}$	$\bar{2}4\bar{2}1$ $2\bar{4}2\bar{1}$	$2\bar{4}21$ $\bar{2}4\bar{2}\bar{1}$	$000\bar{1}$ 0001	c
* 0	$5\bar{1}0$ −12′	510 −12′	$5\bar{2}0$ −23′	520 −23′							100 0′	010 0′
1		610 −7′	$7\bar{3}0$ −17′		$5\bar{4}0$ 20′	430 −18′		230 −2′		130 −11′		
2	$4\bar{1}0$ 10′	710 −20′		310 −17′	$6\bar{5}0$ 21′	750 −18′	$3\bar{5}0$ −3′					
3	$7\bar{2}0$ 1′		$2\bar{1}0$ −29′	720 15′		320 4′	470 −26′	570 −6′	$2\bar{7}0$ 9′			
4				410 24′				340 16′				
5	$3\bar{1}0$ 29′		$7\bar{4}0$ −38′			530 1′					$7\bar{1}0$ 17′	
6		100 23′	$5\bar{3}0$ −29′	510 2′	$1\bar{1}0$ 7′	740 −8′		450 2′	$1\bar{4}0$ 14′	250 −28′	$6\bar{1}0$ 30′	
7	$5\bar{2}0$ 23′			610 7′			$1\bar{2}0$ −15′	560 8′		370 24′	$5\bar{1}0$ 25′	
8	$7\bar{3}0$ 29′		$3\bar{2}0$ −26′	710 −6′		210 1′		670 −7′			$4\bar{1}0$ −13′	
9											$7\bar{2}0$ −22′	
10	$2\bar{1}0$ 17′		$7\bar{5}0$ 12′		$6\bar{7}0$ 9′	730 13′			$1\bar{5}0$ −5′			
11		$7\bar{1}0$ −6′	$4\bar{3}0$ 12′		$5\bar{6}0$ 24′	520 7′					$3\bar{1}0$ 6′	
12	$7\bar{4}0$ 8′	$6\bar{1}0$ 7′	$5\bar{4}0$ −10′		$4\bar{5}0$ 18′		$3\bar{7}0$ 26′	110 −9′		120 −17′		
13	$5\bar{3}0$ 17′	$5\bar{1}0$ 2′	$6\bar{5}0$ − 9′	100 23′	$3\bar{4}0$ −28′	310 13′	$2\bar{5}0$ −26′		$1\bar{6}0$ −5′		$5\bar{2}0$ 0′	
14			$7\bar{6}0$ 17′								$7\bar{3}0$ 6′	170 −6′
15	$3\bar{2}0$ 20′	$4\bar{1}0$ 24′			$5\bar{7}0$ 10′	720 −15′			$1\bar{7}0$ −17′			
16	$7\bar{5}0$ −2′	$7\bar{2}0$ 15′				410 −6′		650 5′		470 −28′	$2\bar{1}0$ −6′	160 6′
17	$4\bar{3}0$ −2′	$3\bar{1}0$ −17′	$1\bar{1}0$ −23′	$7\bar{1}0$ −20′	$2\bar{3}0$ 14′			540 4′		350 −5′		
18	$5\bar{4}0$ −24′			$6\bar{1}0$ −7′		510 −28′	$1\bar{3}0$ −9′	430 26′			$7\bar{4}0$ −15′	
19	$6\bar{5}0$ −23′	$5\bar{2}0$ −23′		$5\bar{1}0$ −12′		610 −23′		750 26′			$5\bar{3}0$ −6′	150 6′
20	$7\bar{6}0$ 3′	$7\bar{3}0$ −17′			$3\bar{5}0$ 13′					230 −4′		
21			$6\bar{7}0$ −21′	$4\bar{1}0$ 10′	470 −10′			320 −12′			$3\bar{2}0$ −3′	
22		$2\bar{1}0$ −29′	$5\bar{6}0$ −6′	$7\bar{2}0$ 1′			$2\bar{7}0$ 11′			570 −8′	$7\bar{5}0$ −25′	
23			$4\bar{5}0$ −12′					530 −15′		340 14′	$4\bar{3}0$ −25′	140 25′
24	$1\bar{1}0$ 23′		$3\bar{4}0$ 2′	$3\bar{1}0$ 29′		100 7′		740 −24′				
25		$7\bar{4}0$ 22′			$1\bar{2}0$ 1′		$1\bar{4}0$ 16′			450 0′	$5\bar{4}0$ 13′	
26			$5\bar{7}0$ −20′	$5\bar{2}0$ 23′				210 −15′		560 6′	$6\bar{5}0$ 14′	270 20′
27		$3\bar{2}0$ −26′		$7\bar{3}0$ 29′						670 −9′		
28	$5\bar{6}0$ −20′		$2\bar{3}0$ −16′					730 −3′				
29	$4\bar{5}0$ −26′	$7\bar{5}0$ 12′		$2\bar{1}0$ 17′	$3\bar{7}0$ −18′	$7\bar{1}0$ 10′	$1\bar{5}0$ −3′	520 −9′	010 −11′			

TABLE 7 (*Continued*).

CALCULATED PRINCIPAL COINCIDENCES BETWEEN MUSCOVITE (001) AND TOURMALINE $(10\bar{1}0)$
Divergence from exact coincidence as given. Observed coincidences indicated by asterisk.

Tourm. $c\wedge$ muscov. 010	$\bar{1}2\bar{1}8$ $1\bar{2}1\bar{8}$	$1\bar{2}18$ $\bar{1}2\bar{1}\bar{8}$	$\bar{1}2\bar{1}4$ $1\bar{2}1\bar{4}$	$1\bar{2}14$ $\bar{1}2\bar{1}\bar{4}$	$\bar{1}2\bar{1}2$ $1\bar{2}1\bar{2}$	$1\bar{2}12$ $\bar{1}2\bar{1}\bar{2}$	$\bar{1}2\bar{1}1$ $1\bar{2}1\bar{1}$	$1\bar{2}11$ $\bar{1}2\bar{1}\bar{1}$	$\bar{2}4\bar{2}1$ $2\bar{4}2\bar{1}$	$2\bar{4}21$ $\bar{2}4\bar{2}\bar{1}$	$000\bar{1}$ 0001	c
* 30		$4\bar{3}0$ 12′				$6\bar{1}0$ 23′					$1\bar{1}0$ 0′	130 0′
31	$3\bar{4}0$ −12′	$5\bar{4}0$ −10′	$3\bar{5}0$ −17′	$7\bar{4}0$ 8′	$2\bar{5}0$ −10′	$5\bar{1}0$ 18′		310 −3′		110 −11′		
32		$6\bar{5}0$ −9′		$5\bar{3}0$ 17′		$4\bar{1}0$ −20′	$1\bar{6}0$ −3′	720 29′				
33	$5\bar{7}0$ 26′	$7\bar{6}0$ 17′	$4\bar{7}0$ 20′			$7\bar{2}0$ −29′						
34	$2\bar{3}0$ −30′			$3\bar{2}0$ 20′			$1\bar{7}0$ −15′	410 −22′		760 29′	$6\bar{7}0$ 2′	
35				$7\bar{5}0$ −2′		$3\bar{1}0$ −1′		510 16′		650 3′	$5\bar{6}0$ 17′	250 −17′
36		$1\bar{1}0$ −23′	$1\bar{2}0$ −29′	$4\bar{3}0$ −2′	$1\bar{3}0$ 7′			610 21′		540 2′	$4\bar{5}0$ 11′	
37				$5\bar{4}0$ −24′		$5\bar{2}0$ −7′		710 8′		430 24′		370 −25′
38	$3\bar{5}0$ 29′			$6\bar{5}0$ −23′		$7\bar{3}0$ −1′				750 24′	$3\bar{4}0$ 25′	
39	$4\bar{7}0$ 6′			$7\bar{6}0$ 3′							$5\bar{7}0$ 3′	
40		$6\bar{7}0$ −21′			$2\bar{7}0$ 27′	$2\bar{1}0$ −13′				320 −14′		
41		$5\bar{6}0$ −6′	$3\bar{7}0$ 12′								$2\bar{3}0$ 7′	20 −6′
42		$4\bar{5}0$ −12′			$1\bar{4}0$ −28′	$7\bar{4}0$ −22′		100 9′		530 −17′		
43	$1\bar{2}0$ 17′		$2\bar{5}0$ 20′	$1\bar{1}0$ 23′		$5\bar{3}0$ −13′			170 5′	740 −26′		
44		$3\bar{4}0$ 2′									$3\bar{5}0$ 6′	
45		$5\bar{7}0$ −20′				$3\bar{2}0$ −10′			160 17′	210 −17′	$4\bar{7}0$ −17′	470 −17′
46												350 6′
47	$3\bar{7}0$ −2′	$2\bar{3}0$ −16′	$1\bar{3}0$ −23′	$5\bar{6}0$ −20′	$1\bar{5}0$ 13′	$7\bar{5}0$ 28′		$6\bar{1}0$ −21′		730 −5′		
48				$4\bar{5}0$ −26′		$4\bar{3}0$ 28′	010 −9′	$5\bar{1}0$ −26′	150 17′	520 −11′		
49	$2\bar{5}0$ 6′					$5\bar{4}0$ 6′					$1\bar{2}0$ −6′	230 7′
50		$3\bar{5}0$ −17′		$3\bar{4}0$ −12′	$1\bar{6}0$ 13′	$6\bar{5}0$ 7′		$4\bar{1}0$ −4′		310 −5′		
51			$2\bar{7}0$ −3′					$7\bar{2}0$ −13′		720 27′		570 3′
? 52		$4\bar{7}0$ 20′		$5\bar{7}0$ 26′	$1\bar{7}0$ 1′							340 25′
53								$3\bar{1}0$ 15′	140 −24′	410 −24′	$3\bar{7}0$ −25′	
54	$1\bar{3}0$ 23′		$1\bar{4}0$ 2′	$2\bar{3}0$ 30′		$1\bar{1}0$ −7′				510 14′		450 11′
55		$1\bar{2}0$ −29′						$5\bar{2}0$ 9′		610 19′	$2\bar{5}0$ −17′	560 17′
56								$7\bar{3}0$ 15′	270 −29′	710 6′		670 2′
57	$2\bar{7}0$ −17′			$3\bar{5}0$ 29′								
58			$1\bar{5}0$ −17′	$4\bar{7}0$ 6′		$6\bar{7}0$ −5′		$2\bar{1}0$ 3′				
59						$5\bar{6}0$ 10′			130 11′			
* 60	$1\bar{4}0$ −12′	$3\bar{7}0$ 12′				$4\bar{5}0$ 4′		$7\bar{4}0$ −6′			$1\bar{3}0$ 0′	110 0′

TABLE 7 (*Continued*)

CALCULATED PRINCIPAL COINCIDENCES BETWEEN MUSCOVITE (001) AND TOURMALINE $(10\bar{1}0)$
Divergence from exact coincidence as given. Observed coincidences indicated by asterisk.

Tourm. $c \wedge$ muscov. 010	$\bar{1}2\bar{1}8$ $1\bar{2}1\bar{8}$	$1\bar{2}18$ $\bar{1}2\bar{1}\bar{8}$	$\bar{1}2\bar{1}4$ $1\bar{2}1\bar{4}$	$1\bar{2}14$ $\bar{1}2\bar{1}\bar{4}$	$\bar{1}2\bar{1}2$ $1\bar{2}1\bar{2}$	$1\bar{2}12$ $\bar{1}2\bar{1}\bar{2}$	$\bar{1}2\bar{1}1$ $1\bar{2}1\bar{1}$	$1\bar{2}11$ $\bar{1}2\bar{1}\bar{1}$	$\bar{2}4\bar{2}1$ $2\bar{4}21$	$2\bar{4}21$ $\bar{2}4\bar{2}\bar{1}$	$000\bar{1}$ 0001	c
61			$1\bar{6}0$ −17′					$5\bar{3}0$ 3′		100 11′		
62		$2\bar{5}0$ 20′		$1\bar{2}0$ 17′		$3\bar{4}0$ 18′	170 3′					
63			170 −29′			570 −4′		$3\bar{2}0$ 6′				
64							160 15′	$7\bar{5}0$ −16′	250 −6′		$2\bar{7}0$ 20′	650 14′
65	$1\bar{5}0$ 29′					$2\bar{3}0$ 0′		$4\bar{3}0$ −16′				540 13′
66		$1\bar{3}0$ −23′		$3\bar{7}0$ −2′	010 −7′				370 −14′	$6\bar{1}0$ −19′		
67							150 15′	$5\bar{4}0$ 22′		$5\bar{1}0$ −24′	$1\bar{4}0$ 25′	430 −25′
68	$1\bar{6}0$ 29′			$2\bar{5}0$ 6′		$3\bar{5}0$ −1′		650 23′				750 −25′
* 69						470 −24′				$4\bar{1}0$ −2′		320 −3′
70	$1\bar{7}0$ 17′	$2\bar{7}0$ −3′							120 5′	$7\bar{2}0$ −11′		
71											$1\bar{5}0$ 6′	530 −6′
72							140 −26′	$1\bar{1}0$ 9′		$3\bar{1}0$ 17′		740 −15′
73		$1\bar{4}0$ 2′		$1\bar{3}0$ 23′		$1\bar{2}0$ −13′						
74							270 29′		470 −6′	$5\bar{2}0$ 11′	$1\bar{6}0$ 6′	210 −6′
75									350 17′	$7\bar{3}0$ 17′		
76				$2\bar{7}0$ −17′				$6\bar{7}0$ 11′			$1\bar{7}0$ −6′	730 6′
77		$1\bar{5}0$ −17′	010 −23′					$5\bar{6}0$ 26′		$2\bar{1}0$ 5′		520 0′
78						$3\bar{7}0$ 28′	130 9′	$4\bar{5}0$ 20′	230 18′			
? 79				$1\bar{4}0$ −12′		$2\bar{5}0$ −24′		$3\bar{4}0$ −26′		$7\bar{4}0$ −4′		310 6′
80		$1\bar{6}0$ −17′			170 −13′				570 14′	$5\bar{3}0$ 5′		
81								$5\bar{7}0$ 12′				720 −22′
82		$1\bar{7}0$ −29′			160 −1′				340 −24′	$3\bar{2}0$ 8′		410 −13′
83							250 −8′	$2\bar{3}0$ 16′	450 22′	$7\bar{5}0$ −14′		510 25′
84	010 −23′			$1\bar{5}0$ 29′		$1\bar{3}0$ −7′			560 28′	$4\bar{3}0$ −14′		610 30′
85					150 −1′		370 −16′		670 13′			710 17′
86								$3\bar{5}0$ 15′		$5\bar{4}0$ 24′		
87				$1\bar{6}0$ 29′				$4\bar{7}0$ −8′		$6\bar{5}0$ 25′		
88						$2\bar{7}0$ 13′						
89				$1\bar{7}0$ 17′	140 18′		120 3′		110 11′			
* 90											010 0′	100 0′

Definite maxima, identifying positions of preferred orientation of the inclusions, can be recognized in Table 5 (Gilsum). These positions are found, from Table 7, to correspond to major calculated coincidences, made by *c* with 010, 130, 110 and 320. Furthermore, there seems to be a tendency towards orientation in positions corresponding to coincidences of *c* with 100, 310 and 340, although the maxima are not well-defined statistically.

In Table 6 (New York City), well-defined maxima are present at positions corresponding to calculated coincidences made by *c* with 010, 110 and 100.

Table 5. Observed Orientations of Tourmaline (10$\bar{1}$0) upon Muscovite (001). Gilsum, N. H.

Reference directions: $c\wedge010$

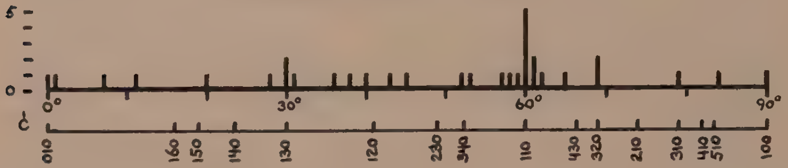
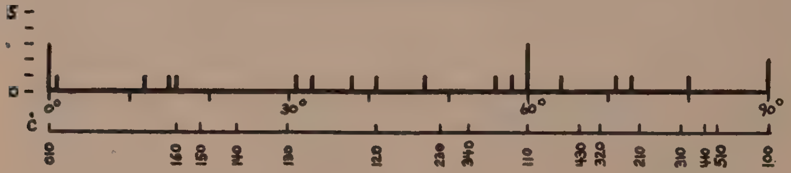


Table 6. Observed Orientations of Tourmaline (10$\bar{1}$0) upon Muscovite (001). New York City

Reference directions: $c\wedge010$



The relative frequency of the various observed orientations differs for the two localities, as in the case of the inclusions flattened on (11$\bar{2}$0). The relative frequency of the various observed orientations also differs between inclusions flattened on (11$\bar{2}$0) and on (10$\bar{1}$0), and varies independently for the two localities. This fact indicates that the coincidences made by the *c* direction alone upon (001) of muscovite do not act independently, but that other coincidences in the contact planes, characteristic of the particular plane of flattening, act in conjunction with *c* in controlling orientation. The percentage of crystals flattened on (11$\bar{2}$0) and on (10$\bar{1}$0) is also different for the two localities.

Habit and Orientation of Inclusions Flattened on (0001)

Crystals flattened on (0001) were found to comprise 16.7% of the total number of inclusions observed from Gilsum, and 22.9% of the

TABLE 8

CALCULATED PRINCIPAL COINCIDENCES BETWEEN MUSCOVITE (001) AND TOURMALINE (0001)
Divergence from exact coincidence as given. Observed coincidences indicated by asterisk.

Tourm. $11\bar{2}0\wedge$ muscov. 010	$10\bar{1}0$ $\bar{1}010$	$\bar{1}100$ $1\bar{1}00$	$0\bar{1}10$ $01\bar{1}0$	$11\bar{2}0$ $\bar{1}\bar{1}20$	$1\bar{2}10$ $\bar{1}2\bar{1}0$	$2\bar{1}\bar{1}0$ $\bar{2}110$	$21\bar{3}0$ $\bar{2}\bar{1}30$	$12\bar{3}0$ $\bar{1}\bar{2}30$	$\bar{3}210$ $3\bar{2}\bar{1}0$	$2\bar{3}10$ $\bar{2}3\bar{1}0$	$1\bar{3}20$ $\bar{1}3\bar{2}0$	$\bar{3}120$ $3\bar{1}\bar{2}0$
* 0	130 0′	100 0′	$1\bar{3}0$ 0′	010 0′	$1\bar{1}0$ 0′	110 0′			530 1′	$5\bar{3}0$ 1′	$2\bar{3}0$ 0′	230 0′
1									740 −8′			
2										$3\bar{2}0$ 4′		570 −4′
3							170 1′		210 1′	$7\bar{5}0$ −18′	$3\bar{5}0$ −1′	340 18′
4			$2\bar{7}0$ 20′		$6\bar{7}0$ 2′	650 14′				$4\bar{3}0$ −18′	$4\bar{7}0$ −24′	
? 5	250 −17′	$7\bar{1}0$ 17′			$5\bar{6}0$ 17′	540 13′	160 13′		730 13′			450 4′
6		$6\bar{1}0$ 30′			$4\bar{5}0$ 11′				520 7′	$5\bar{4}0$ 20		560 10′
7	370 −25′	$5\bar{1}0$ 25′	$1\bar{4}0$ 25′			430 −25′				$6\bar{5}0$ 21′		670 −5′
8		$4\bar{1}0$ −13′			$3\bar{4}0$ 25′	750 −25′	150 13′		310 13′		$1\bar{2}0$ −13′	
9		$7\bar{2}0$ −22′			$5\bar{7}0$ 3′	320 −3′						
10									720 15′			
? 11	120 −6′	$3\bar{1}0$ 6′	$1\bar{5}0$ 6′		$2\bar{3}0$ 7′	530 −6		010 0′	410 − 6′	$1\bar{1}0$ 7′		110 −7′
12						740 −15′						
13		$5\bar{2}0$ 0′					140 −28′		510 −28′		$3\bar{7}0$ 28′	
14		$7\bar{3}0$ 6′	$1\bar{6}0$ 6′	170 −6′	$3\bar{5}0$ 6′	210 −6′			610 −23′		$2\bar{5}0$ −24′	
15	470 −17′				$4\bar{7}0$ −17′		270 27′			$6\bar{7}0$ 9′		650 7′
16	350 6′	$2\bar{1}0$ −6′	$1\bar{7}0$ −6′	160 6′		730 6′				$5\bar{6}0$ 24′		540 6′
17						520 0′				$4\bar{5}0$ 18′		430 28′
18		$7\bar{4}0$ −15′								$3\bar{4}0$ −28′		750 28′
* 19	230 7′	$5\bar{3}0$ −6′		150 6′	$1\bar{2}0$ −6′	310 6′	130 7′		100 7′		$1\bar{3}0$ −7′	
20										$5\bar{7}0$ 10′		320 −10′
21	570 3′	$3\bar{2}0$ −3′				720 −22′						
22	340 25′	$7\bar{5}0$ −25′				410 −13′				$2\bar{3}0$ 14′		530 −13′
23		$4\bar{3}0$ −25′		140 25′	$3\bar{7}0$ −25′	510 25′					$2\bar{7}0$ 13′	740 −22′
24	450 11′					610 30′	250 −10	170 1′	$7\bar{1}0$ 10′			
25	560 17′	$5\bar{4}0$ 13′			250 −17′	710 17′			$6\bar{1}0$ 23′	$3\bar{5}0$ 13′		210 −13′
26	670 2′	$6\bar{5}0$ 14′		270 20′			370 −18′	160 13′	$5\bar{1}0$ 18′	$4\bar{7}0$ −10′	$1\bar{4}0$ 18′	
27									$4\bar{1}0$ −20′			730 −1′
28									$7\bar{2}0$ −29′			520 −7′
29												
* 30	110 0′	$1\bar{1}0$ 0′	010 0′	130 0′	$1\bar{3}0$ 0′	100 0′	120 1′	150 −1′	$3\bar{1}0$ −1′	$1\bar{2}0$ 1′	150 −1′	310 −1′

total number of inclusions observed from New York City. The basal inclusions rarely exceed 1 mm. in diameter, and were readily recognized by their habit and by the absence of pleochroism and birefringence.

The basal inclusions in the Gilsum muscovite have a symmetrical hexagonal outline (Fig. 1); rarely an additional set of three or of six minor modifying faces is present. The bounding faces of the hexagonal crystals can not be identified with certainty, but must belong either to $(11\bar{2}0)$, or to $(10\bar{1}0)$ and $(01\bar{1}0)$ in combination. Since $(01\bar{1}0)$ is usually subordinate in development to $(10\bar{1}0)$ when these forms occur together, the equant outline of the crystals suggests that the bounding form is $(11\bar{2}0)$. This interpretation is supported by the fact that $(11\bar{2}0)$ is characteristic of the crystals that are flattened in the prism zone from this locality. The additional three or six modifying faces are evidently those of $(10\bar{1}0)$ and $(01\bar{1}0)$. A number of the inclusions do not possess straight sides, but are rounded or irregularly developed.

The basal inclusions in the New York City muscovite are twelve-sided (Fig. 2), with $(11\bar{2}0)$, $(10\bar{1}0)$ and $(01\bar{1}0)$ as the bounding forms. The crystals are usually distorted in such manner as to prevent the separate identification of the several forms. On a few crystals the habit was dominated by a triangular set of three faces; these faces were assumed to belong to $(10\bar{1}0)$.

The orientation of the inclusions to the muscovite can be defined, as with the prismatic inclusions, by stating the position of a direction in the plane of flattening relative to a direction in (001) of the muscovite. In Table 8 the calculated coincidences for a few directions of relatively low indices in tourmaline (001) and muscovite (001) are tabulated for values of the angle tourmaline $11\bar{2}0 \wedge 010$ muscovite. The symmetry of these basal plates restricts the range of measurement to 0°–30°.

Table 9. Observed Orientations of Tourmaline (0001) upon Muscovite (001). Gilsum, N. H., and New York City

Reference directions: $11\bar{2}0 \wedge 010$

Orientation	Gilsum, N. H.	New York City
Percussion figure 010, 110, $1\bar{1}0$	39	6
Pressure figure 100, 130, $1\bar{3}0$	14	2
Perc. or press. fig.; undetermined	4	7
19° position (Table 8)	9	3
11° position (Table 8)	?	?
5° position (Table 8)	?	
Other positions	29	6
Position unknown	24	1
Total number observed	119	25

The observed orientations of the basal inclusions are cited in Table 9. The orientation can be definitely stated only when a bounding form—reference direction—can be identified. Inclusions on which the position of $(11\bar{2}0)$ is known and which make angles of 0°, 30° and 60°, without respect to sign, with muscovite 010 for the various faces of this form are oriented to the rays of the percussion figure, while inclusions in which the angles are 30°, 60° and 90° are oriented to the rays of the pressure figure (Fig. 1). However, if the actual position of a reference direction, such as $11\bar{2}0$, could be identified in the inclusions, as in the case of those flattened in the prism zone, in which the position of *c* is readily determinable, the range of measurement would be 90° and it very probably would be found that the orientation varies with respect to the several rays of the percussion and pressure figures. A number of twelve-sided crystals on which the separate forms could not be identified were noted to be oriented to both the pressure and percussion figures (the interfacial angles being 30°); these crystals were tabulated separately.

A number of inclusions occurred at values of $11\bar{2}0 \wedge 010$ (taken as the minimum angle made by a face of $(11\bar{2}0)$ with muscovite 010) between 0° and 30°, as follows:

Gilsum: 2, 3, 4, 5, 5, 5, 6, 7, 8, 9, 10, 11, 11, 12, 12, 13, 15, 16, 16, 17, 18, 18, 18, 18, 19, 19, 19, 19, 20, 20, 21, 22, 23, 25, 26, 26, 27, 28

New York City: 3, 7, 11, 12, 15, 18, 19, 19, 26

From these values a marked tendency can be recognized for orientation at an angular position of 19°, and ill-marked tendencies for orientation as 11° and 5°. As is seen from Table 8, these orientations correspond to calculated coincidences between directions of relatively low indices in the tourmaline and the muscovite, although the coincidences are not as marked as at the 0° (percussion figure) and 30° (pressure figure) positions. It is difficult, however, to identify the particular direction or directions in the tourmaline to whose coincidences the orientation can be referred.

In calculating the percentages of orientation at each position (see Summary), inclusions whose orientation was uncertain or undeterminable were distributed among the recognized orientations in proper proportion.

Since the parallel forms—pedions—(0001) and $(000\bar{1})$ of tourmaline are unlike in structure, it can be presumed that the orientation of the basally flattened inclusions also varies with respect to these forms. Hemimorphic crystals, including tourmaline, tend to attach themselves to a substrate by a particular pole of the polar axis.[12]

---

[12] Holzner, J., *Zeit. Krist.*, vol. 65, pp. 175–179, 1927.

Discussion

It is generally found in oriented growths that the surface of contact is characterized by the coincidence of crystal planes with similar atomic arrangements and in which the atomic spacings are equal or small multiples. The fact of orientation in such instances is usually immediately apparent by reason of a parallelism among the overgrowing crystals, or by the parallelism of obvious crystallographic characters of the overgrowing and substrate crystals. The recognition of orientation has been ordinarily confined to growths showing such features. Growths which are not arranged in such manner and which seemingly are randomly distributed upon the substrate, or which do not appear to satisfy the particular conditions of crystallographic coincidence mentioned, have been termed unoriented.

On the other hand, it may be considered that a degree of frequency is associated with each of an infinitude of crystallographic orientations between contact growths of any two species. The term unoriented then would not apply to any over- or inter-growing crystal. The various positions of crystallographic orientation, each of different overall coincidence, may be expressed discontinuously by reference to particular directions in the contact surface. It is apparent, on such a basis, that the relative frequency of the various orientations would have to be investigated by a statistical method. It is also necessary to apply a statistical method in a theory relating orientation to specific, limiting conditions of crystallographic coincidence to establish the fact of random distribution in all but the postulated positions.

In the present study, the inclusions appeared on casual examination to be unoriented to the muscovite. Tendencies for orientation, however, became apparent on statistical study, and the number of orientations thus established increased with increasing number of measurements. Further, in the present stage of development of the graphs, the observations that occur between the established orientations, and which can not be recognized statistically as being oriented, do not appear to be distributed by chance. For instance, in Table 2 such observations are more concentrated in the regions from 1° to 8°, 42° to 48°, 54° to 58°, and 62° to 67°, than in the regions from 9° to 25°, 35° to 38°, 75° to 78° and 81° to 89°. If these observations were of chance origin, uninfluenced by considerations of crystallographic coincidence with the mica, they would be equally distributed in these regions. The fact that they are unequally distributed indicates, on the contrary, that their origin has been controlled. Presumably the statistical population or the accuracy of measurement is insufficient to define the separate positions of orientation.

A definite indication that on increasing the number of observations, additional planes of flattening, with orientations thereon, will also be established, is found in the fact that separate plotting of $c \wedge 010$ of the inclusions from both localities identified as being flattened other than on (0001), $(11\bar{2}0)$ or $(10\bar{1}0)$, the exact plane of flattening being unknown, yielded a graph with a well-defined maxima at 60°.

It can not be concluded, however, that the number of orientations established will increase indefinitely with increasing number of observations, as it may be that the observations are not sufficiently numerous to exhaust a given range of specific orientations, and beyond which only random distribution would be found. Nevertheless, a view relating orientation to a frequency basis could be regarded as being established as a general law, if it were found invariably that the recognition of orientations between two species of crystals depended only on the extent of statistical investigation. On such a basis, orientation would be more frequent in positions of relatively high coincidence, inasmuch as crystallization from solution upon a substrate tends to be so ordered that crystallographically similar planes in the overgrowing and substrate crystals coincide.[13]

Growths of low coincidence, and of low frequency, have been obtained experimentally in the limiting case of complete identity of structure of the overgrowing and substrate crystals, as with growths of K alum upon K alum.[14] Such so-called heterotwins or heterogrowths, in which the position of the overgrowing crystal can not be expressed by any operation of symmetry, as in ordinary twins, have also been observed with quartz, feldspar and other species. In general, in the case of complete identity or near identity of structure between two crystals, the frequency of orientation in positions other than that of complete conformability would be relatively small. With increasing dissimilarity in structure, the percent of occurrences oriented in any one position would decrease, and the relative frequency of the different orientations would approach each other in value. The fact of orientation would then go unrecognized on casual examination, and a large number of observations would be necessary to establish even the more frequent positions of orientation. With a close similarity of structure in a few planes and a general dissimilarity in the other planes, the like planes would be loci of orientations of relatively high frequency, and a wide interval would separate them statistically from orientations in the unlike planes.

The greatest number of orientations previously recognized for a pair of substances seem to be those for the exsolution growths of hematite in feldspar, for which 10 different contact planes, with an undetermined number of orientations thereon, have been found.[15] A greater number of orientations would be expected for a given number of observations of intergrowths than for the same number of observations of overgrowths, inasmuch as the opportunity for orientation in positions of relatively high coincidence is not restricted to the coincidences of a particular substrate plane.

---

[13] Frondel, C., *Am. Jour. Sci.*, ser. 5, vol. **30**, p. 54, 1935.

[14] Schubnikov, A., and Schaskolsky, M., *Zeit. Krist.*, vol. **85**, pp. 1–16, 1933.

Associated Minerals

In addition to the tourmaline, the following minerals were observed as inclusions in the Gilsum muscovite: albite, beryl, biotite, garnet, magnetite, smoky quartz (in sheets 1 mm. or so thick and 100 sq. cms. and more in area), zoisite fibers, and abundant deep brown particles, occasionally developed into dendrite-like growths, of hematite. The magnetite and the hematite growths were readily seen to be oriented parallel to either the percussion or pressure figures of the mica.

In a few instances the tourmaline inclusions were partly or completely surrounded by a narrow irregular border of greenish biotite. Magnetite crystals were observed to abut against or to be molded on tourmaline crystals. The muscovite laminae are not bent around the tourmaline inclusions, but are intersected by and interfinger with the tourmalines. The two minerals have crystallized simultaneously, and the inclusions represent overgrowths that have been enclosed by the continued growth of the muscovite. Occasionally the tourmaline inclusions are arranged in indistinct rows outlining zones of growth in the mica.

A variety of minerals were observed as inclusions in the New York City muscovite. Primary inclusions, enclosed during the growth of the muscovite crystals, included apatite, actinolite, biotite, dumortierite, garnet, hematite, magnetite, quartz, and unidentified minerals in minute acicular and pin-point crystals, frequently surrounded by pleochroic halos. Secondary inclusions, apparently deposited in cleavage openings by meteoric solutions, included chalcedony, calcite, siderite and pyrite. Goethite, limonite, bright-red spherules of turgite (?), and a pale greenish blue unidentified mineral, possibly a sulphate containing ferrous iron, occurred as alteration products of the pyrite. The goethite crystals showed a marked tendency for orientation parallel to the percussions and the pressure figures of the mica. A parallel arrangement was also noted among some of the quartz and pyrite inclusions.

---

[15] Andersen, O., *Am. Jour. Sci.*, ser. 4, vol. **40**, p. 364, 1915.

ACKNOWLEDGMENTS

The writer is indebted to Mr. George E. Ashby for opportunity to examine the specimens from New York City, to Mr. Herbert P. Whitlock of the American Museum of Natural History for the specimens from Gilsum, N. H., and to Prof. Paul F. Kerr, Columbia University, for a critical reading of the manuscript.

AN INEXPENSIVE TABLE FOR POLISHING ORES

J. H. HATTON, *University of Arizona, Tucson, Arizona.*

Increasing interest in polished section technique has created a need for a suitable machine for polishing ore specimens. Up to the present most of the polishing wheels used in metallographic and mineragraphic laboratories have been of the Sauveur-Boylston type.[1] This consists of two disks approximately 6 inches in diameter which are attached to the projecting ends of the armature shaft of an electric motor. The disks thus revolve in vertical planes. Cloths of different types are fastened to the disks by means of brass hoops. The cloths usually employed are sheeting for coarser polishing powders, such as the finer grades of carborundum or alundum, chromic oxide, and rouge, and billiard cloth for magnesia or "black magnetic rouge." The disadvantages of this type of polishing wheel are:

1. The abrasive tends to fly off the wheel.
2. The effort of holding the specimen against the vertical disk is much greater than with a horizontal wheel.

On the other hand, with the horizontal wheel gravity tends to retain the abrasive and aids the operator in maintaining a steady pressure of the specimen against the cloth.

Horizontal laps are in use in a number of institutions and in most places have been constructed locally.

Machines for polishing specimens are manufactured by a few companies. These are highly satisfactory but are too expensive for most institutions to permit their purchase.

An inexpensive and effective machine was designed and constructed by Professor A. J. Eardley in the Department of Geology of the University of Michigan. This design was modified somewhat by the present writer, and a polishing table was constructed by him in the Department of Geology of the University of Arizona in September, 1935. It has been in use for more than six months and has proved very satisfactory. The present paper describes this polishing table.

The details of the table are shown in Plates I and II and in Figs. 1 and 2 and are largely self-explanatory. The cost of the table completely equipped is about $110, depending on the cost of labor. As shown in the plans, the table supports two horizontally revolving laps, but a third lap can be installed at an additional expense of about $30 by increasing the length of the table 12 inches.

---

[1] Described in Murdoch, J.: *Microscopical determination of the opaque minerals*, p. 19, New York, **1916.**

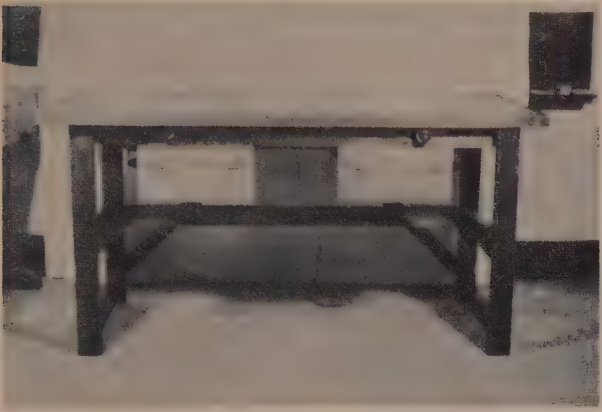


Fig. 1. Eardley-Hatton Polishing Table.

The table proper is of simple wood construction (Plate I) and is made unusually rugged in order to minimize vibration. The table is first constructed and the outside is stained brown and then varnished. The shaft and bearings of each lap are then mounted on two boards $1\frac{1}{2}'' \times 6'' \times 17''$. Details of this mounting are shown in Plate II, Fig. 1b.

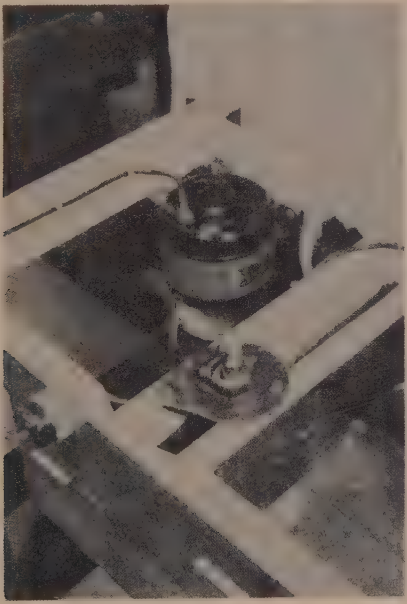


Fig. 2. Details of Mounting

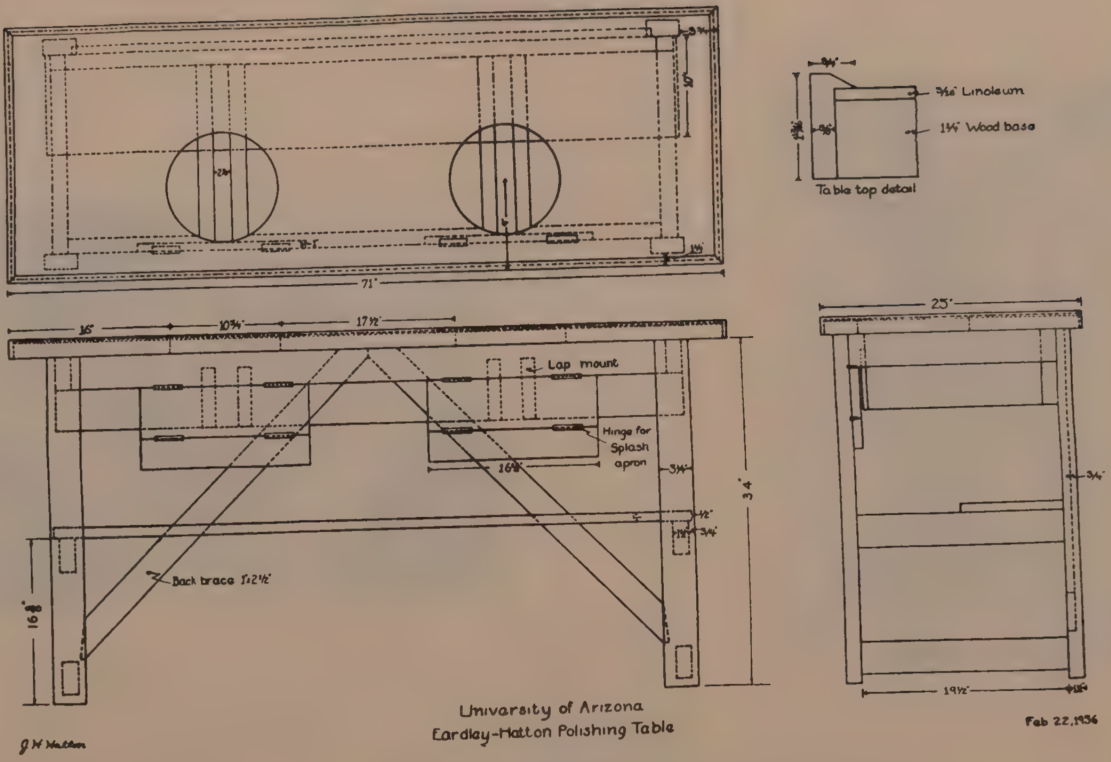


PLATE I. Construction of the table.

The bearings are Delco-Remy generator bearings and were designed for the generators of Plymouth automobiles. Only the end plates and bearings of the generator are used. The lower bearing of the table is a simple ball bearing.

The bearing hole into which the shaft fits is made of special hard steel and can be reamed only with much trouble, hence the shaft must be turned so as to fit snugly in the bearing; this has an inside diameter of 43/64 inches. It was found advisable to knurl that portion of the shaft which fits in the bearing. The upper thrust bearing acts merely as a guide. The bushing is slightly smaller than is necessary for the $\frac{1}{2}$-inch shaft and must be reamed to fit the shaft.

The catalogue number of the Delco-Remy ball (lower) bearing is 817223; that of the thrust (upper) bearing is 1853830. It will be found necessary to have 5/16″ holes drilled in the bearing plates in order that they may be readily attached. The holes already present are not suitably located for immediate use.

The bearings are attached to the $1\frac{1}{2}''\times 6''\times 17''$ boards by means of $\frac{1}{4}''\times 2\frac{1}{2}''$ lag screws. The upper bearing is first screwed onto the boards, the shaft inserted and allowed to hang freely. The lower plate and bearing is centered and attached by similar screws. It is necessary at this stage to have the bearings exactly at right angles to the axis of the shaft, otherwise the shaft will bind, causing wear with attendant vibration of the lap. The life of the bearings will be considerably lessened by any unnecessary wear. After the end plates have been attached, the shaft will bind and the screws must be manipulated. The use of shims may be necessary if it is found that the plates have been slightly misplaced. To test the freeness of the shaft, the lower pulley should be attached and rotated slowly by hand. Tight places will readily be "felt." The shaft, upon being rotated rapidly, should continue its rotation for several revolutions by inertia.

The lap assembly should then be mounted into the table by wood screws at the front and by lag screws at the back. It will be found that the laps have again been thrown out of line and that a "freeing" is again necessary. This may be accomplished by again manipulating the screws which hold the bearing plates. The same tests for freeness should again be applied.

The shafts are provided with a cut-away portion to allow the set screw of the driven pulley to be well seated. At the top of the shaft a cross head pin is placed which fits into the lap. This serves as a safety to prevent all possible slippage.

Individual motors are used to permit independent operation of each lap. The motors are $\frac{1}{4}$h.p. Kenmore 110-volt A.C. with 1750 R.P.M. and are supplied by Sears, Roebuck and Co. The driver pulley is 5 inches in diameter and the driven pulley 6½ inches in diameter, the latter turns the shaft 1350 R.P.M. This speed of revolution has been found by trial to be the most satisfactory for a 5-inch lap. A faster speed tends to pull the specimen from the hands and to cause too much abrasive to fly off the wheel, whereas excessively slow speeds prolong the time of polishing. The belts are 42-inch V-shaped fan belts. Pulleys and belts were likewise obtained from Sears, Roebuck and Co. The motor is mounted onto the back of the table in such a position that the slack of the belt is taken up. The belts should not be too tight as centrifugal force would soon cause excessive wear in the motor and lap bearings.

The laps are shown in Plate II, Fig. 5. They are brass castings machined on the upper surface. They can be obtained from the Metallurgical Laboratory of the University of Michigan, Ann Arbor, for approximately $2.00 each. The laps do not screw onto the shaft but have tapered sockets which fit onto the tapered upper end of the shaft. As all of the laps of this type made at the University of Michigan have the same size of internal taper, the shaft must be turned to fit this socket. Hence it is advisable to obtain one of the laps before having the shafts made, so that the machinist can fit them properly. With a close fit between the taper of the shaft and the socket of the lap, the latter is held sufficiently firm during the polishing to prevent slipping. On stopping the wheel, the lap can be removed almost instantaneously with a moderate upward jerk. The ease of changing laps makes it advisable to keep a lap for each type of abrasive thus eliminating the need for frequent changing of cloths.

Laps of greater diameter than 5 inches are likewise made at the University of Michigan and have the same size of socket as the 5-inch lap and can therefore be used in this machine. However, a larger sized lap necessitates a slowing down of the motor, otherwise the peripheral speed would be greater than that of the 5-inch lap. Larger sized laps are also unnecessarily wasteful of cloth as the cloth must be replaced upon the appearance of the smallest hole or tear.

The splash pan (Plate II, Fig. 3a) is made of sheet metal and can be constructed locally by a tinsmith. It has a drain to facilitate the cleaning of the lap pans. Hoses need not be attached at all times as the operations are not particularly wet. If such is the case rubber stoppers should be used to plug the holes.

Splash pan covers may or may not be provided (see Plate II, Fig. 4). If the laps are not detached from the shafts, they should be covered; but if they are placed in a cabinet when not in use the covers are not

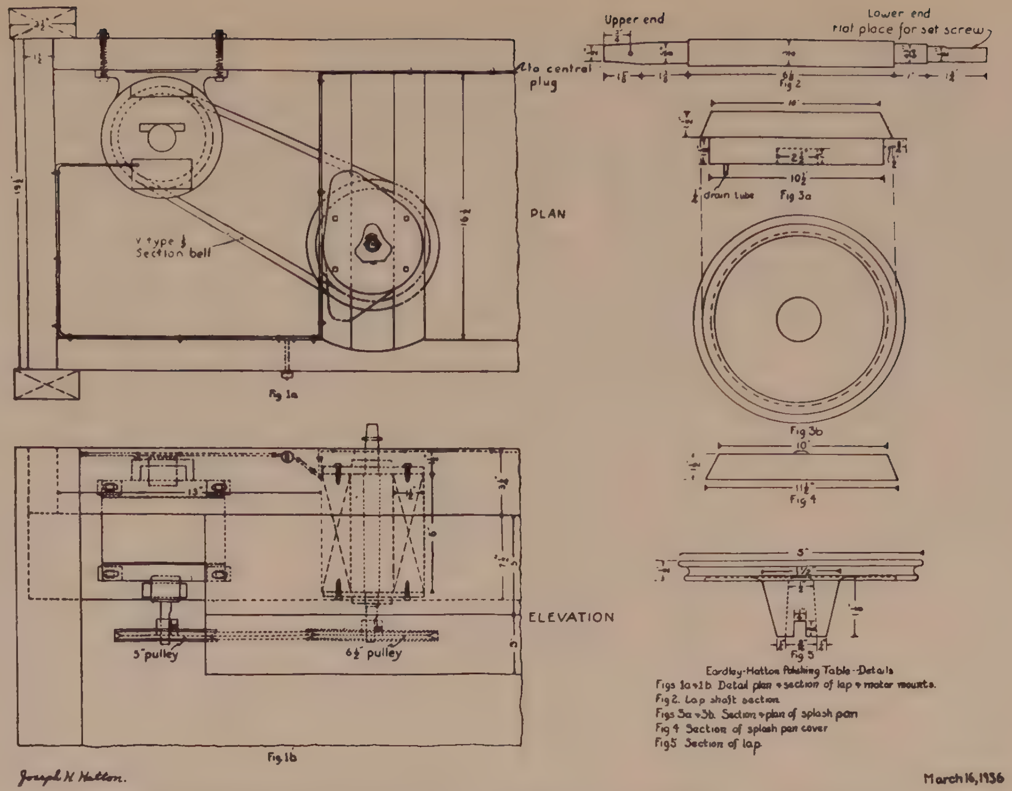


PLATE II. Detail of the construction of the laps, electrical system, etc., as well as the accessories to the table.

necessary. If the grinding machine is in the same room as the polisher, the covers are an absolute necessity.

A heavy 3/16″ linoleum is cemented to the table top and is kept highly waxed. Thus any splashing may be wiped off very easily and this feature contributes much to the appearance of the laboratory.

The top is placed on the table after all other work has been completed and is attached by four 4-inch wood screws, one in each corner post. This allows the top to be removed in a few minutes time to facilitate the oiling of the motors and lap bearings. This should be done once every two weeks at least. Caution must be used so that one does not apply an excessive amount of lubricant as this merely flows into the motor and down on the pulleys. From here it is thrown off to smear the wall or the operator. The splash aprons in front of the table catch most of this excess oil.

The cloth may be attached to the lap in several ways. The first is by use of elastic bands, which fit into the groove at the periphery of the lap. This is a satisfactory method if the bands are tight. However, the cloth may pull loose upon the fatiguing of the bands.

The second method tried is that of the use of a solid spring steel bar which has been bent to fit the lap. If the ring does not fit snugly, small loose places will appear in the cloth. These cause excessive wear and rips, and often pull the specimen from the hand.

The third and best method yet devised is by the use of a 3/16″ coiled spring made of No. 20 wire. The spring must be strong but naturally can be considerably weaker than that indicated by the second method. The spring is cut and the ends joined either by wiring, welding, or by the use of a hook and eye. The cloth is easily put on and the wrinkles removed by this method.

Both motors are driven from a central 2-plug base plate. The base plate is fed by a single electrical line thus eliminating one unnecessary lamp cord.

If the laps develop static electricity they should be grounded by a fine copper wire.

COST SHEET

Table (construction and wood)	$17.00
2 Kenmore motors, 1750 R.P.M., ¼ h.p. @ $6.95	13.90
2 5″ V-type pulleys @ $.60	1.20
2 6½″ V-type pulleys @ $.75	1.50
2 42″ V-type belts @ $.60	1.20
4 5″ laps @ $2.00	8.00
2 switches @ $.25	.50
2 shafts (made to order) @ $6.00	12.00
2 splash pans @ $2.50	5.00

2 generator end plates @ $1.00	2.00
2 generator end plate assemblies (ball-bearing) @ $5.00	10.00
1 base plate—two hole @ $.50	.50
1 plug, electrical	.10
15′ wire @ $.10 per ft	1.50
10′ rubber hose @ $.10 per ft	1.00
2 splash pan covers @ $1.50	3.00
linoleum, 72″×25″, 3/16″ heavy	5.00
1 pt. paste to cement linoleum	.25
6′ of ⅛ coiled spring @ $.20 (for lap cloth retainer)	1.20
Miscellaneous (nuts, bolts, etc.)	2.00
Labor for installation, etc.	20.00
Total approximate cost	$107.85

The polishing machine is kept in the same laboratory as the microscopes and opaque sections, thus allowing frequent polishings during identification of the mineral.

Suggestions for Construction of a Grinding Table

A grinding table may be constructed according to the same design as that of the above described polishing table. The grinding laps are usually 10 inches in diameter, hence wider holes must be provided on the table top. If a three-lap table is desired, the entire table should be lengthened 15 inches. This would allow for a distance of 78½ inches outside dimensions between supporting posts and an overall table top length of 86 inches. The lap holes should be cut with their centers 11½ inches from the edge of the table and the holes should be 15 inches in diameter. The centers of the holes should be 25 inches apart.

The grinding laps are metal disks of 1-inch thickness. Brass laps like those used in the polishing machine are used as bases for the disks. The disks are attached to the brass laps by means of lag bolts ⅜″ in diameter and 7/16″ long. Four holes are drilled through the brass laps to accommodate four holes similarly placed in the disks. The holes in the brass laps are not threaded but the holes in the disks have threads which fit similar threads at the ends of the bolts. The holes in the disks should not be over ⅜″ deep so that the life of the disks may be prolonged as much as possible.

Care must be taken that the center of the disk coincides with the center of the shaft, otherwise vibration and undue wear on the bearings will result.

The advantages of this type of grinding machine are:

1. Metal disks are less expensive than large-sized laps which are provided with screw threads or other methods of attachment.

2. Worn or uneven disks may be machined easily.

If only two laps are provided, cast iron is preferable for coarse grinding and wrought iron for fine grinding. The cast iron lap is made by casting a disk of the requisite diameter and thickness, followed by machining of one surface and the periphery. The wrought iron laps are cut from a 1-inch sheet of boiler plate, usually by means of an acetylene torch, followed by machining of the periphery. If the surfaces are not sufficiently smooth, one of them must be machined.

The third lap, if provided, is made of copper and is used for the finest grinding abrasives. Copper laps are used for this purpose at Columbia University and at the California Institute of Technology. Concentric grooves are cut on the surface of the copper to prevent grabbing of the specimen.[2]

The laps on the grinding table should not be run faster than 750 R.P.M., otherwise the abrasive will not remain on the lap. The best set of pulleys which could be used with the Kenmore motor above described is a 3″ driver pulley and a 7″ driven pulley.

The writer wishes to express his thanks to Professor M. N. Short of the University of Arizona for encouragement and criticism.

---

[2] Directions for cutting such grooves are given by J. W. Vanderwilt: Improvements in the polishing of ores: *Econ. Geol.*, vol. **23**, p. 307, 1928.

NOTES AND NEWS

X-RAY STUDY OF PUCHERITE

W. F. De Jong and J. J. De Lange,

Lab. voor Delfstofkunde, Technische Hoogeschool, Delft.

Investigations have been carried out recently on the structure of pucherite from Schneeberg, Saxony. Using rotating crystal photographs (Fe $K_{\alpha\,\&\,\beta}$ radiation) it has been possible to determine the following values for the crystallographic axes:

$a = 5.38$ Å; $b = 5.04$ Å; $c = 11.98$ Å. (Accuracy ± 0.03 Å.)

$a:b:c = 1.069:1:2.379$ (macroscopic: $a:b:c = 0.5327:1:2.3357$).

Assuming the mineral to be rhombic and the cell containing 4 mol. $BiVO_4$, the specific gravity would be 6.57, which value differs considerably from the one known in mineralogical literature (6.25).[1]

Owing to lack of suitable material the authors have not been able to carry out specific gravity determinations (by direct method) with satisfying accuracy. Also owing to the rarity of well crystallized single crystals we have not been able to determine the space group with certainty.

CALCITE TWINS FROM NORTH PLAINFIELD, NEW JERSEY

Alfred C. Hawkins

In the basalt quarry, operated by the Somerset Trap Rock Corporation, in the First Watchung Mountain, located on Somerset Street, between North Plainfield and Watchung in Somerset County, calcite occurs in considerable quantities as a filling in the breccia of nearly vertical fault zones. Crystals showing complex combinations of rhombohedral and scalenohedral forms, very commonly twinned, line the walls of occasional open cavities in the breccia. Among these, probably the most remarkable are two heart-shaped twins which were obtained by the writer in the summer of 1935. These occurred together in a cavity about 8 inches deep and 4 inches wide; the walls of this cavity were completely covered with smaller calcite crystals of more ordinary scalenohedral and rhombohedral habits, the majority of which were twinned according to the same law as the two larger crystals, but not exhibiting the heart-shaped form.

The larger of the twinned crystals measures 4×4×2 cm. in size, and is transparent, with a light yellow color due to a slight trace of iron. The smaller crystal is 2×2×1 cm., and is in every way similar to the larger one, except that it exhibits several small faces which are poorly developed. In the case of each there is also a development, on the side and base of the main twinned crystal, of subsidiary crystals composed of the scalenohedron $(21\bar{3}1)$ and a steep rhombohedron whose faces are rounded; these latter crystals are in parallel position with respect to the main twin.

---

[1] Frenzel, A. *Neues Jahrbuch*, p. 515, **1872.**

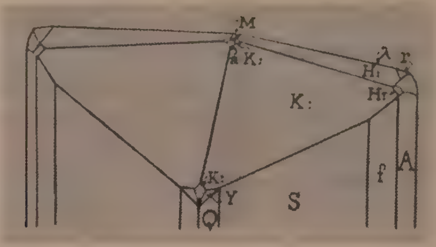


FIG. 1

The faces of these calcite crystals are sharp and lend themselves readily to either the contact or reflection methods of angle measurement. Faces of the scalenohedron $(21\bar{3}1)$ are nearly perfect, there being a slight etching in the form of microscopic, irregular pits. Faces in the minus rhombohedron zone $(04\bar{4}3$ to $07\bar{7}1)$ are translucent, due rather to crystal overgrowth than to actual pitting. Faces of the scalenohedron $(31\bar{4}2)$, which are narrow bands along the upper edges of each crystal, are rough and are striated parallel to the edge $(31\bar{4}2 \wedge 10\bar{1}1)$. The faces of the unit plus rhombohedron $(10\bar{1}1)$ are very rough and poorly developed.

The crystallographic forms, most of which are designated by their Roman letters in the drawing (Fig. 1) are as follows:

Prism:		
Gdt.	*Dana*	
a	*a*	$(11\bar{2}0)$
Scalenohedrons:		
Gdt.	*Dana*	
K:	*v*	$(21\bar{3}1)$
H:	λ	$(31\bar{4}2)$
Y:	—	$(12\cdot 32\cdot \overline{44}\cdot 13)$
Rhombohedrons (+)		
Gdt.	*Dana*	
$p^{\cdot}$	*r*	$(10\bar{1}1)$
$m^{\cdot}$	*M*	$(40\bar{4}1)$
$R^{\cdot}$	—	$(20\bar{2}1)$
Rhombohedrons (−)		
Gdt.	*Dana*	
$\xi^{\cdot}$	*A*	$(04\bar{4}3)$
$\phi^{\cdot}$	*f*	$(02\bar{2}1)$
$\Xi^{\cdot}$	*s*	$(05\bar{5}1)$
$Q^{\cdot}$	—	$(07\bar{7}1)$

The twin plane $(01\bar{1}2)$ is shaded in the figure.

Quarrying operations now in progress in the vicinity of this vein of calcite may uncover other interesting crystals for study.

Grateful acknowledgment is hereby made to Mr. Herbert P. Whitlock, whose experience with the forms of calcite enabled the writer to start correctly with the solution of this crystallographic problem.

ADAMITE FROM CHLORIDE CLIFF, CALIFORNIA

JOSEPH MURDOCH, *University of California at Los Angeles.*

Specimens of an undetermined mineral collected at Chloride Cliff, Inyo County, California, were submitted to the writer for identification and proved to be the rather rare zinc arsenate, adamite. This mineral was originally discovered at Chañarcillo, Chile in 1886, and first found in the United States in 1916, in the Tintic district, Utah,[1] later at Cedar Mountain, Mineral County, Nevada,[2] and more recently at Gold Hill, Tooele County, Utah.[3]

At Chloride Cliff the mineral occurs as small crystals, scattered or closely packed, on the surface of fragments of crystalline limestone, in the oxidized zone of workings in this locality. It is the latest mineral to be formed here, overlying crusts of associated limonitic material, crumbly, secondary calcite, and a green mineral which was not identified, but which appears from chemical tests to be one of the hydrous arsenates of copper. This green mineral is quite closely associated with the adamite, and even in some cases causes the latter to appear green on casual inspection. The adamite, however, is perfectly colorless, and where it appears green, closer examination shows it to be superimposed on cores of the other mineral, which show through, and seem to color the whole. There is no transition between the two, and the line of demarcation is perfectly sharp. Much of the adamite is entirely free from the green substance and it is material of this type which was used in the tests.

The blowpipe, physical and optical properties of the mineral identify it as adamite, and the crystal measurements confirm the identification. Owing to the small amount of pure material available it was unfortunately not possible to make a quantitative analysis, but qualitative tests, made for the writer by Professor W. R. Crowell of the Chemistry Department of the University of California at Los Angeles, indicated the absence of all bases except zinc. This, with the lack of coloration in the mineral, renders it reasonable to assume that it approaches closely to the theoretical formula for this species: $4\,ZnO \cdot As_2O_5 \cdot H_2O$. The specific gravity of a colorless crystal was determined with Clerici solution to be just below 4.3. Optical tests, using white light, gave the following results:

---

[1] Means, A. H., *Am. Jour. Sci.*, (4) vol. **41**, p. 125, 1916.

[2] Knopf, A., *U. S. Geol. Surv.*, Bull. **725**, p. 372, 1921.

[3] Staples, L. W., *Am. Mineral.*, vol. **20**, p. 371, 1935.

Biaxial positive; $n=1.720$, $\beta=1.740$ $\gamma=1.745+$. $2V=90^\circ\pm$

CRYSTALLOGRAPHY

Most of the crystals were too imperfect to measure, but three or four were found which were reasonably complete, and the forms present were determined on the two circle goniometer. Similar faces were noted on many of the imperfect crystals, so that the measured forms seem to be characteristic for the occurrence. The axial ratio used, $a:b:c=0.996:1:0.718$, was that determined by Laspeyres[4] for colorless material from Laurium, Greece, on the assumption that this ratio would apply to equally pure material.

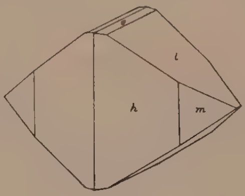


Fig 1

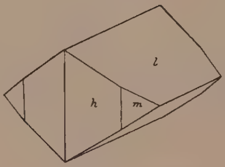


Fig. 2

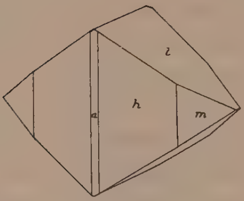


Fig. 3

Measurement showed that the Chloride Cliff crystals were relatively simple, showing three common forms on all the individuals, with two other forms less well developed, on one or two of them. The common forms were the prisms *m* {110}, and *h* {210}, and the brachydome *l* {011}. One crystal showed a narrow development of the brachydome *e* {013} (an unusual form), and another a very narrow and poorly developed pinacoid *a* {100}. Hintze[5] lists 32 forms, of which the usual ones are the prisms {110}, {120}, {210}; the brachydome {011}; and the macrodome {101}. The Chloride Cliff crystals show two types of habits: (1) nearly equidimensional crystals with the prisms and brachydome about equally developed (Figs. 1 and 3) which is the more common type; (2) the same faces are present, but elongated parallel to the *a* axis (Fig. 2). In distinction from the Gold Hill occurrence, the macrodome is entirely absent. Colorless crystals from Laurium also show two habits: type 1, prismatic parallel to *b*; and type 2, prismatic parallel to *c*. The Chloride Cliff mineral thus affords a new occurrence, and also a new habit for the species.

---

[4] Laspeyres, H., *Zeit. Krist.*, vol. **2**, p. 147, 1878.

[5] Hintze, *Handbuch der Mineralogie*, vol. **1**, Sect. 4 part 1, p. 643.

BOOK REVIEWS

INTERPRETATIVE PETROLOGY OF THE IGNEOUS ROCKS by HAROLD LATTIMORE ALLING. Octavo xv+353 pages, 48 figs., 11 plates. McGraw-Hill, New York, 1936. Price $4.00.

This book has as its expressed aim the interpretation of the igneous rocks rather than their description and for the most part the plan is adhered to throughout.

The author begins, appropriately, by discussing the principles upon which interpretation must be based, the principles of chemical equilibrium. The treatment is necessarily brief, in some instances perhaps all too brief. In the discussion of the application of the phase rule (p. 13) only one condition, that of invariancy (in a condensed system), is described. It is doubtful whether the student will readily apprehend how the equation applies to the less simple univariant or divariant system, in other words to a system in which the degrees of freedom are greater than zero. It is unfortunate, too, that the author should make the statement "The phase rule enables the petrologist to predict the composition of igneous rocks in terms of components and hence the composition of minerals can be approximated when equilibria are complete." The plain fact is that the phase rule is only a mathematical equation, though a very useful one, and enables only the prediction of the *number* of phases that can coexist at equilibrium under given sets of conditions. The nature and composition of the phases can be determined only by the laborious process of experimental investigation of the equilibrium diagram.

In treating the change of composition of crystalline compounds during crystallization, from the point of view of reaction between liquid and crystals, the author has failed to grasp (p. 46) the reason why the reaction taking place at an incongruent melting point (peritectic point of the author) has been referred to as a discontinuous reaction. The term discontinuous was used by the reviewer to emphasize the discontinuous change of composition of the crystalline phase (phases) as contrasted with the continuous change of composition in a solid solution series. No question of the incongruent melting taking place at a definite temperature was involved for it is well known and has been observed in many systems that if the number of components and therefore the number of degrees of freedom are great enough, the incongruent melting takes place through a range of temperature. The characteristic feature, discontinuous change of *composition*, persists however.

The discussion of the various groups of rock-forming minerals giving range of chemical composition, the corresponding variation of physical properties and the determined diagrams of phase equilibrium occupies some 80 pages. This section will no doubt prove the most useful part of the book.

The chapter on the crystallization of magmas discusses the various views that have been expressed on this subject and makes some use of the equilibrium diagrams of investigated silicate systems. In the use of these diagrams it would have been of great advantage to the student if the actual construction lines tracing the course of crystallization of individual mixtures had been shown on the diagram. Indeed the author himself has fallen into error for lack of such lines. Thus he says (p. 214) that in the albite-anorthite-diopside system the course of crystallization of a mixture in the plagioclase field "can be traced by drawing a construction line . . . perpendicularly to the isotherms." This is incorrect. Courses of crystallization are not perpendicular to isotherms except accidentally. Again, in discussing crystallization in the diopside-forsterite-silica system (pp. 216–217) and speaking of a melt "rich in Mg_2SiO_4, forsterite, and . . . indicated in Fig. 39 C by a dot in the lower left-hand corner of the triangle in the forsterite field" he says "The last liquid disappears and the whole consists of pyroxene, shown by a point on the peritectic line." It is impossible for a melt having the chosen composition to crystallize entirely to pyroxene. Moreover the compositions of pyroxenes are not given by points on the peritectic line (i.e. the forsterite-pyroxene boundary curve) but are given by points on the diopside-$MgSiO_3$ conjugation line, a line not shown in his diagram, Fig. 39 C.

In discussing magmatic differentiation the author sets down the various points of view that have been expressed. This is true also of his remarks upon assimilation. Here the application of the reviewer's "reaction principle" to the problem of assimilation is discussed, but unfortunately the application is not always correctly made. Thus on p. 246 the author says "Magmas dissolve minerals of inclusions that are higher in the reaction series" which is an incorrect statement of the reviewer's conclusion. On the other hand on p. 249 he says " . . . granitic magmas cannot *dissolve* basic rocks" which is a correct statement of the reviewer's conclusion regarding precisely the same set of conditions. In the intervening pages the reviewer's conclusions are sometimes correctly and again incorrectly stated.

The chapter on the origin of igneous rocks states briefly the principal views held as to the source of magmas, the nature of parental magmas and the manner in which various rocks have been derived therefrom. Here as in the section on magmatic differentiation, with which the subject-matter is naturally closely related, the author maintains a commendably judicial attitude.

The book is marred by many infelicities of expression, such as that on p. 21 "There are many minerals . . . which melt incongruently. Such an illustration is orthoclase," or again that on p. 336 where it is said of normative minerals " . . . their usefulness has been carried perhaps too far." Genuine naïveté resides in the attribution to Harker of the opinion that "hybrid rocks are barren *of minerals of economic importance*."* Nevertheless the book accomplishes its purpose of gathering together in one place and in English a mass of information and expressions of opinion that are widely scattered in the literature in many languages and the student may well find it a useful addition to his texts on petrology.

Norman L. Bowen

---

* Italics are the reviewer's.

THE STORY OF THE GEMS—A Popular Handbook by Herbert P. Whitlock. Octavo viii+206 pages, with two colored plates, many line drawings, and half-tone cuts. Lee Furman, Inc., New York, **1936**. Price $3.50.

The author's long association with the American Museum of Natural History, as Curator of Minerals and Gems, has given him an unusual opportunity to study the desires of great masses of our population regarding gems. Based upon his varied experience, Dr. Whitlock has incorporated in this volume a large amount of interesting material not commonly found in similar books. Thus, there is special emphasis upon the history and use of gems, and many curious facts about them are included.

Following an introduction in which the important physical properties are briefly described, there are chapters on the Antique Use of Gems, Art of the Lapidary, Forms in which Gems are Cut, The Diamond, Famous Diamonds of the World, Precious Stones Other than the Diamond, Semiprecious Stones, Opaque and Ornamental Stones, Unusual Gem Stones, and Organic Products Used as Gems. There is also a well-selected bibliography, and a table summarizing the important properties of gems, which should prove useful in their determination. The text is well illustrated, and the author is to be commended for the many excellent half-tone cuts. The appearance of this volume is to be welcomed as a very helpful addition to the literature, in book form in the English language, on gem stones, in which there has been a growing public interest in recent years.

EDWARD H. KRAUS

MINERALOGIE by R. BRAUNS. Seventh revised edition. 146 pages, 132 figures. Sammlung Göschen. Walter de Gruyter, Berlin, **1936**. Price in cloth binding, 1.62 R.M.

This small but well-known manual on Mineralogy makes its appearance in a new revised edition. The presentation follows the general arrangement of the earlier issues with such changes and additions as to bring the book up-to-date, insofar as the limited space will permit.

About 40 pages are devoted to geometrical crystallography with descriptions and line drawings of the more common crystal forms; the physical and chemical properties of minerals, and methods of formation are discussed in 25 pages, while about half of the text, or 75 pages, are devoted to descriptions of over 100 minerals.

The book is intended to give the beginner a general survey of the subject and this purpose has been achieved as the author with his long experience as a teacher has made a wise selection and has presented the material clearly.

W. F. H.

PROCEEDINGS OF SOCIETIES

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences of Philadelphia, June 4, 1936

A stated meeting of the Society was called to order by Mr. Arndt; 39 members and 27 visitors being present. Experiences of the various members in collecting their most interesting specimens were described.

Field trips were reported by Mr. Morgan from the American Copper Mine, Somerville, N.J., (native copper specimens from dumps), Paterson, N.J., (analcite, natrolite, pectolite, prehnite), Strickland's Quarry (green tourmaline, columbite, garnet); and by Mr. Moyd, above the Easton Verdolite Quarry (smoky quartz).

W. H. FLACK, *Secretary*

Academy of Natural Sciences of Philadelphia, September 3, 1936

A stated meeting was called to order by President W. Arndt, 41 members and 18 visitors being present. The subject for the evening was "Reports of Summer Trips." The speakers and the localities visited included: Harold W. Arndt, Lake Clear and Cantley, Canada; Leonard A. Morgan, Moore Station, Blackwood and Kirby's Mills, N. J., Amelia Court House, Va., and Spruce Pine, N. C.; Edmund H. Cienkowski, western localities; Samuel G. Gordon, Joplin District; Albert Jehle, western localities; Joseph L. Gillson, Newfoundland to examine a fluorspar deposit; Louis Moyd, Goat Hill and Bernardsville,

N. J.; Wm. C. Knabe, Perkiomenville and Bridgeport, Pa.; Elmer Benge, West Conshohocken and Henderson Station, Pa.; G. Earle Thompson, Audubon, Bridgeport and Media, Pa.; Charles Durbin and party camped nine days at Phoenixville digging in old dumps.

W. H. FLACK, *Secretary*

NEW YORK MINERALOGICAL CLUB

American Museum of Natural History, New York City, October 21, 1936

President B. T. Butler presided at the first Fall meeting with 81 members and guests present. The business meeting dealt principally with the approaching 50th anniversary celebration, which will take the form of a banquet at the Museum in November.

The remainder of the meeting was devoted to reports of members upon their collecting experiences during the summer. Miss Catherine Schroder reported upon a rather unprofitable visit to Hawaii, where she attempted to collect from some localities described by Eakle, but found most of them inaccessible or unproductive.

Daniel T. O'Connell told of the mineral collecting experiences of the Rainbow Bridge-Monument Valley expedition. He described one very promising radium prospect near the Mitten Buttes, almost on the Arizona, Colorado, Utah, New Mexico boundary corner. Carnotite and hewettite were said to be abundant.

J. A. Taylor told of an interesting trip through Europe, with visits to the salt mines of Berchtesgaden and the granite quarries of Baveno.

O. I. Lee had just returned from a visit to the vicinity of Spruce Pine, where he visited many of the mines. The McKinney Mine is said to be very active and has a large dump rich in columbite, samarskite, sphalerite and other interesting minerals. The large Glen Mine is the source of white and blue hyalite. Nearby is the No. 20 Mine, on Crabtree Creek, from which the first clarkeite specimens came. From the Smith Mine come thulite crystals in feldspar, as well as garnet, apatite, and uranium minerals. A new mine in Ash County is reported to yield large beryl crystals with gem possibilities, perfect large smoky quartz crystals and crystals of columbite which weigh as much as twenty pounds. A thirteen pound mass of the latter mineral was exhibited.

F. H. Pough described two trips to the Strickland Quarry, Portland, Conn., where some rare minerals were found. The first visit produced some loose fragments of very deeply etched beryl, on which masses of small white tabular crystals of bertrandite were found. One specimen was collected containing two crystals of microlite in a matrix of the late potash-bearing albite which replaces the cleavelandite. Lithiophilite was abundant. The second trip produced more bertrandite, this time in more prismatic crystals in vugs in feldspar, and apparently later than the late albite.

F. H. POUGH, *Secretary*

MINERALOGICAL SOCIETY OF AMERICA

SEVENTEENTH ANNUAL MEETING

William S. Bayley, *President*
Paul F. Kerr, *Secretary*

Cincinnati, Ohio
December 29–31, 1936

The annual meeting of *The Mineralogical Society of America* will be held in the Netherland Plaza Hotel in conjunction with the Geological Society of America. It is planned to hold three sessions. The first session will be on Tuesday, December 29th at 2:00 P.M. and the second session on Thursday, December 31st at 9:30 A.M. A joint session with the Geological Society of America for the presentation of papers on petrographic subjects will be held on Wednesday, December 30th at 2:00 P.M.

The *presidential address* of Dr. William S. Bayley, retiring president of the Mineralogical Society of America, entitled *Mineralogy's Contribution to the Other Sciences and to Industry* will be presented before the general session of all societies on Wednesday morning.

An informal luncheon for all members of the Mineralogical Society and their friends will be held at 12:30 on Wednesday, December 30th.

In view of the fact that reduced railroad rates are now in effect, no certificates are being offered for the use of Society members.

Preliminary List of Papers

George H. Anderson and Donald D. MacLellan—**An Unusual Feldspar from the Northern Inyo Range.**

Charles B. Behre, Jr.—**Mineralogy of the Wisconsin Lead-Zinc Ores.**

Harry Berman—**The Structural Lattice and Classification of Bustamite.**

Norman L. Bowen—**The System $NaAlSiO_4$-FeO-SiO_2.**

M. J. Buerger—**The Valences of Iron in Pyrite and Marcasite.**

———— **An Apparatus for the Precision Determination of Single Crystal Lattice Constants.**

———— **The Weissenberg Treatment of Crystals Belonging to the Oblique Systems.**

N. W. Buerger—**The Unit Cell and Space Group of Sternbergite.**

John W. Butler, Jr.—**On the Time Required to Form the Olivine Zone in the Palisades Sill, New Jersey.**

J. D. H. Donnay—**The Crystallographic Series of Baumhauer and Ungemach, a Theoretical Consequence and Factual Confirmation of the Law of Bravais.**

R. C. Emmons—A Universal Stage Method of Determining Birefringence.

R. C. Emmons and Ray Wilcox—A Mineralogic Study of Silicosis.

H. W. Fairbairn—Enantiomorphous Quartz in Tectonites.

John W. Gruner—Unusually High Feldspar Content of the Glenwood Shale.

——— Some Notes on the Structure of Stilpnomelane.

George R. Heyl—The Lamprophyres of the Bay of Exploits, Newfoundland.

Edward H. Kraus—Observations on the Production of Synthetic Gems.

John T. Lonsdale—The Plantersville Meteorite, Grimes County, Texas.

Charles H. Moore, Jr.—The Staurolite Belts of Patrick and Henry Counties, Virginia.

M. A. Peacock—On Normal Triclinic Face-Symbols and the Harmonic Arithmetic Rule.

M. A. Peacock and M. C. Bandy—Ungemachite and Clino-ungemachite: New Minerals from Chile.

Terence T. Quirke—2E Goniometer.

Terence T. Quirke and Louis C. McCabe—Refractive Indices of Vitrains.

L. S. Ramsdell—Crystallography and Unit Cell of Synthetic Burkeite.

Austin F. Rogers—The Symmetry of Ice.

J. F. Schairer—The Ternary System, Leucite-Diopside-Silica.

Benjamin M. Shaub—Paragenesis of the Uranium-Bearing and Associated Minerals Occurring Northeast of Grafton Center, New Hampshire.

C. B. Slawson—Checking Index Liquids with a Microscope.

H. T. V. Smith—Simplified Graphic Method of Determining Approximate Axial Angle from Refractive Indices of Biaxial Minerals.

Lester W. Strock—Defect Lattices in Crystal Structures.

——— The Distribution of Lithium in Rocks and Minerals as Revealed by Quantitative Spectrum Analysis.

W. A. Tarr—The Trend of Mineralogical Research.

George Tunell and C. J. Ksanda—The Crystal Structure of Krennerite.

William D. Urry—Helium Ratio of Florida Anhydrite.

A. N. Winchell—Further Studies of the Zeolites.

INDEX TO VOLUME 21

Leading articles are in **bold face type**; notes, abstracts and reviews are in ordinary type. Only minerals for which definite data are given are indexed.

Adamite from Chloride Cliff, California. (Murdoch) 811
Aguilarite from Comstock lode, Virginia City, Nevada. (Coats) 532
Ahlfeld, D. 270
Aidyrlite (Godlevsky) 269
Akermanite 193
Alexander, A. E. Locality for opalized spherules 266
——— 199
Allemontite, *x*-ray study of. (Holmes) 202
Allen, V. T. Dickite from St. Louis, Missouri 457
——— **Mineralized spherulitic limestone in the Cheltenham fireclay** 369
Alling, H. L. Interpretative petrology of igneous rocks. [Book review] 813
Al-atoms in the two reaction series, role of. (Brammall) 268
Amarillite. (Ungemach) 270
Ammonium molybdo-ditellurate, crystallography of. (Donnay, Mélon) 250
Amygdaloidal dikes. (Moehlman) 329
Andalusite in pegmatite. (Murdoch) 68
Anderson, B. W. 140
Anorthite from Duke Island, Alaska. (Glass) 201
Antigorite 463, 494
Anterlite, *x*-ray powder data for. (Waldo) 71
Arsenoferrite, probable non-existence of. (Buerger) 70
Arsenopyrite group, crystal structure of. (Buerger) 203
Asbestos, minerelogy of. (Syromyatnikov) 48
Augelite. (Pough) 536
"Autoliths," orientation of minerals in. (Pabst) 68
Babingtonite and epidote from Westfield, Mass. (Palache) 193, 652
Bacalite. (Buddhue) 269
Baier, E. and Schmidt, W. Lehrbuch der Mineralogie. [Book review] 267
Balk, R. and Krieger, P. Devitrified felsite dikes from Ascutney Mt., Vermont 516
Baltimorite 463
Barber, C. T. 388
Barite in red beds of Colorado. (Howland) 584
Barth, T. F. W. 204
——— Book review 331
Bastite 463
Bates limestone, Lewiston, Maine, minerals in. (Fisher) 200, 321
Beiyinite. (Ho) 214
Bentonitic magnesian clay-mineral. (Foshag, Woodford) 238
Berman, H. 201
Bermanite, a new phosphate, occurring with triplite in Arizona. (Hurlbut) 656
Berthierite, crystallographic data, unit cell and space group. (Buerger) 205, 442
Bertrandite and epistilbite from Bedford, N. Y. (Pough) 264
Biographisch-literarisches Handwörterbuch für Mathematik, Astronomie, Physik mit Geophysik, Chemie, Kristallographie und verwandte Wissensgebiete. (Poggendorff) [Book review] 535
Blockite. (Herzenberg, Ahlfeld) 270
Boldyrev, A. K. Are there 47 or 48 simple forms possible on crystals? 731
Book of minerals. (Hawkins) [Book review] 74
Borax. (Schaller) 192

Bowen, N. L. and Ellestad, R. B. Nepheline contrasts......... 363
——— Book review............. 813
———.....................193, 678
Bowenite...................... 463
Brammall, A.................268, 388
Brandtite...................... 600
Brauns, R. Mineralogie. [Book review]...................... 815
Brochantite, *x*-ray powder data for. (Waldo)................... 71
Bruner, F. H. Uraninite from Hottah Lake............... 265
Buddhue, J..................... 269
Buerger, M. J. Crystallographic data, unit cell and space group for berthierite ($FeSb_2S_4$)...205, 442
——— **Crystals of the realgar type: symmetry, unit cell and space group of nitrogen sulfide**..... 575
——— **Law of complication**...... 702
——— Probable non-existence of arsenoferrite............... 70
——— **X-ray powder camera**..... 11
———..................203, 205, 206
——— **and Butler, R. D. Technique for construction of models illustrating arrangement and packing of atoms in crystals**.................. 150
——— and Lukesh, J. S. Preparation of oriented polished sections of small single crystals.. 667
Buie, B. F..................... 197
Burri, C....................... 269
Bustamite from Inyo Co., Calif. (Murdoch, Webb)........... 69
Butler, J. W., Jr. Origin of emery deposits near Peekskill, N.Y. 537
——— **with Buerger, M. J. Technique for construction of models illustrating arrangement and packing of atoms in crystals**....................... 150
Buttgenbach, H. Les minéraux et les roches, études pratiques de cristallographie, pétrographie et minéralogie. [Book review] 211
Bytownite, optical data and analysis................... 219
Caesium molybdo-tellurates, crystallography of. (Donnay, Mélon).................... 299
Calaverite. (Tunell, Ksanda)..... 203
Calcic plagioclases, chemical composition and optical properties of. (Phillips, Hess).......... 194
Calcite twins from North Plainfield, N.J. (Hawkins)......204, 809
Callaghan, E................... 198
Cameron, E. N. with Kerr, P. F. Fuller's earth of bentonitic origin from Tehachapi, Calif. 230
Cape Neddick, Maine, dikes of. (Haff)..................... 197
Cases for display and storage of specimens. (Gordon)........ 196
Cassiterite crystals of distorted habit from Pilbara goldfield, western Australia. (Simpson) 140
Cerite, radioactive, deposits near Jamestown, Colo. (Goddard, Glass)..................... 199
Chapman, W. M. Feldspar twinning in a differentiated sill... 33
Chlorite, third study of. (Winchell) 194, 642
Claudetite, occurrence in Imperial Valley, Calif. (Kelley)...... 137
Cleavage of ionic minerals. (Shappell)....................75, 390
Cleveland Mineralogical Society.. 461
Clinoferrosilite. (Bowen)......... 678
Coats, R. R. Aguilarite from Comstock lode, Virginia City, Nev. 532
Complication, law of. (Buerger).. 702
Cordierite, optically positive, in Kisseyenew gneiss at Sherridon, Manitoba. (Rutherford) 386
Cristobalite..................... 689
Crystal forms, 47 or 48 possible? (Boldyrev)................. 731
Cubanite, crystal structure of. (Buerger).................. 205
Cubanite from Sudbury, Ontario. (Peacock, Yatsevitch)....... 55
Cummingtonite from the Black Hills, S. Dakota. (Wayland).. 607
Currier, L. W. Memorial of C. H. Richardson................ 178

Cyclic permutation of crystallographic axes. (Peacock)...... 136

Dana, E. S., memorial of. (Ford).. 173
Danburite, melting of. (Morey, Ingerson).................. 194
Davis, H. T. with Henderson, E. P. Moore County, N. Carolina, meteorite—A new eucrite.... 215
DeJong, W. F. and DeLange, J. J. X-ray study of pucherite.... 809
DeLange, J. J. with DeJong, W. F. Pucherite.................. 809
De Leenheer, L................. 270
Denny, M. V.................. 197
Devitrified felsite dikes from Ascutney Mt., Vermont. (Balk, Krieger)............. 516
Deweylite...................467, 496
Dickite in Missouri. (Tarr, Keller) 109, 195
Dickite from St. Louis, Missouri. (Allen).................... 457
Dielectric constant of mineral powders. (Rosenholtz, Smith) 115
Differentiated igneous intrusion, peculiar form of. (Buie)..... 197
Diopsides from southern California. (Merriam, Laudermilk)..................... 715
Diopside, morphological description and analysis. (Peacock).. 318
Diopside...................... 193
Dodge, T. A. Rapid microscopic method for distinguishing quartz from untwinned oligoclase-andesine 531
Dolomites, castellated, from Major Co. Okla. (Merritt)......... 604
Donnay, J. D. H. [Book review].. 211
——— **and Mélon, J. Crystallography of ammonium molybdoditellurate................** 250
——— ——— **Crystallography of caesium molybdotellurates...** 299
——— ——— **Crystallography of lithium molybdotellurate.....** 125
——— with **Morse, H. W. Optics and structure of three-dimensional spherulites.........201, 391**

Dowie, D. L.................. 268
Drugman, J. L. E.............. 612
Dunham, K. C. Xenoliths in the Organ batholith, N. Mexico.. 312

Edingtonites, substituted, *x*-ray examination of. (Taylor).... 140
Edmundson, R. Phosphatic concretions near Junction City, Ky....................... 529
Ellestad, R. B. with Bowen, N. L. Nepheline contrasts......... 363
Emery deposits near Peekskill, N.Y., origin of. (Butler)..... 537
Emigh, G. D. Improved Vanderwilt rock saw............... 670
Epidote from Westfield, Mass. (Palache)................. 652
Epistilbite from Bedford, N.Y. (Pough).................. 264
Essai de détermination des propriétés optiques d'un minéral par la mesure, en lumière parallele oblique, des retards en différents points d'une lame cristalline. (Mélon) [Review] 331
Eulysites and related rock-types from Loch Duich, Ross-shire. (Tilley)................... 268

Faust, G. T. Fusion relations of of iron-orthoclase, with discussion of the evidence for the existence of an iron-orthoclase molecule in feldspar........ 735
Feldspar, replacing fossils. (Stringham).................... 200
Feldspar twinning in a differentiated sill. (Chapman)........ 33
Fisher, L. W. Minerals in Bates limestone, Lewiston, Maine 200, 321
Fluorite-silica pseudomorphs. (Murdoch)................ 18
Ford, W. E. Memorial of E. S. Dana..................... 173
Foshag, W. F. Ganophyllite and zincian amphibole from Franklin Furnace, N.J....... 63

Foshag, W. F. and Woodford, A. O. Bentonitic magnesian clay-mineral 238
Fraser, D. M. Paleozoic pegmatites in the Pennsylvania highlands 662
Frondel, C. Oriented inclusions of tourmaline in muscovite 777
Fuller's earth of bentonitic origin from Tehachapi, Calif. (Kerr, Cameron) 230

Ganophyllite and zincian amphibole from Franklin Furnace, N.J. (Foshag) 63
Germanium, test for 383
Glass, J. J. 199, 201
——— with Henderson, E. P. Pyroxmangite, new locality; identity of sobralite and pyroxmangite 273
Goddard, E. N. 199
Gabbro near Philadelphia, Penna., alteration of. (Watson) 200
Godlevsky, M. N. 269
Gold and silver in the crystalline rocks of the Malvern Hills. (Brammall, Dowie) 268
Gonyer, F. A. with Larsen, E. S., Irving, J., and Larsen, E. S. 3rd. Petrologic results of a study of the minerals from the Tertiary rocks of the San Juan region, Colo. 679
Gordon, S. G. 196
Greenalite structures, probably identity of. (Gruner) 205
Greenalite, structure and chemical composition. (Gruner) 449
Greig, J. W., Merwin, H. E. and Posnjak, E. Separation planes in magnetite 193, 504
Grossularite (analysis and optical data) 9
Gruner, J. W. Hydrothermal alteration of montmorillonite to feldspar at 245°–300°C. ...201, 511
——— Structure and chemical composition of greenalite ..205, 449
——— Book review 267
——— 204, 205

Hackmanite from Bancroft, Ont., reversible photosensitivity in. (Lee) 764
Haff, J. C. Igneous rock names and their evaluation 427
——— 197
Hatton, J. H. An inexpensive table for polishing ores 800
Hawkins, A. C. Calcite twins from N. Plainfield, N.J. 204, 809
——— Book of minerals. [Book review] 74
Henderson, E. P. and Davis, H. T. Moore County. N. Carolina, meteorite—A new eucrite 215
——— and Glass, J. J. Pyroxmangite, new locality, and identity of sobralite and pyroxmangite 273
Herzenberg, R. 270
Herzenbergite (kolbeckine). (Ramdohr) 677
Hess, H. H. with Phillips, A. H. Metamorphic differentiation at contacts between serpentinite and siliceous country rocks 333
——— 194, 198
Ho, T. L. 214
Hobbs, W. H. Book review 676
Holmes, R. J. 202
Honess, A. P. Book review 676
Howell, D. H. with Kennard, T. G. Spectrographic examination of Siamese zircons 721
Howland, A. L. Occurrence of barite in red beds of Colorado .. 584
Hunt, W. F., Kraus, E. H. and Ramsdell, L. S. Mineralogy. [Book review] 676
Hunt, W. F. Book reviews ...74, 535, 815
Hurlbut, C. S., Jr. A new phosphate, bermanite, occurring with triplite in Arizona 656
——— *X*-ray determination of the silica minerals in submicroscopic intergrowths 727
——— 198
Hutton, C. O. 268
Hydrothermal alteration of montmorillonite to feldspar at 245°–300°C. (Gruner) 201, 511

Hydroxylapatite. (Burri, Jakob, Parker, Strunz)............. 269
Hypersthene, optical data........ 220

Identification of minerals by reflected light. (Wright)...... 200
Igneous rock names and their evaluation (Haff)........... 427
Immersion liquids of high refractive index. (West)........194, 245
Ingerson, E..................... 194
Interpretive petrology of the igneous rocks. (Alling) [Book review].................... 813
Iron orthoclase, fusion relations of, with discussion of evidence for the existence of an iron-orthoclase molecule in feldspar. (Faust).................... 735
Iron strigovite. (Palmquist)...... 269
Irving, J. with Larsen, E. S., Gonyer, F. A. and Larsen, E. S. 3rd. Petrologic results of a study of the minerals from the Tertiary volcanic rocks of the San Juan region, Colo....... 679
Ishkyldite, a new structural variety of chrysotile. (Syromyatnikov).................... 48

Jacob, J...................... 269

Keller, W. D. with Tarr, W. A. Dickite in Missouri.......109, 195
Kelley, V. C. Occurrence of claudetite in Imperial Valley, Calif. 137
Kennard, T. G. and Howell, D. H. Spectrographic examination of Siamese zircons............ 721
Kernite and borax in the Kramer borate field, Calif., origin of. (Schaller)................. 192
Kerr, P. F. Improved specific gravity balance................. 121
——— 198
——— and Cameron, E. N. Fuller's earth of bentonitic origin from Tehachapi, Calif....... 230

Key to precious stones. (Spencer) [Book review].............. 611

Khazanovich, I. K.............. 269
Khibinite (Khazanovich)........ 269
Klockmann's Lehrbuch der Mineralogie. (Ramdohr) [Book review]..................... 535
Kolbeckine (Ramdohr).......... 677
Kraus, E. H., Hunt, W. F. and Ramsdell, L. S. Mineralogy. [Book review]............. 676
——— Book reviews......535, 611, 814
Krennerite, calaverite and sylvanite, relation between structural and morphological elements of. (Tunnell, Ksanda)....... 203
Krieger, P. with Balk, R. Devitrified dikes from Ascutney Mt., Vermont.................. 516
Ksanda, C. J................... 203
Kyanite-eclogites, paragenesis of. (Tilley).................... 612

Laboratory museum collection. (Rogers).................. 196
Lapparent, J. de................ 678
Lapparentite. (Ungemach)....... 332
Larsen, E. S., Irving, J. Gonyer, F. A. and Larsen, E. S., 3rd. Petrologic results of a study of the minerals from the Tertiary volcanic rocks of the San Juan region, Colo.......... 679
Laudermilk, J. D. with Merriam, R. Two diopsides from southern California............. 715
Lee, O. Ivan. A new property of matter: Reversible photosensitivity in hackmanite from Bancroft, Ont............... 764
Leech, J. G. C................. 388
Lehrbuch der Mineralogie. (Klockmann, Ramdohr) [Book review]..................... 535
Lehrbuch der Mineralogie. (Schmidt, Baier) [Book review]..................... 267
Leucoglaucite. (Ungemach)...... 271
Lithium molybdo-tellurate, crystallography of. (Donnay, Mélon) 125
Livingstonite, crystallography of. (Richmond)..............204, 719

Lokka, L. 269
Lukesh, J. C. with Buerger, M. J. Preparation of oriented polished sections of small single crystals 667

Magnesian clay-mineral. (Foshag, Woodford) 240
Magnetite metacrysts. (Schwartz) 635
Magnetite-plagioclase rocks of Magnet Heights, Bushveld, Transvaal. (Wells) 268
Magnetite, separation planes in. (Greig, Merwin, Posnjak) 193, 504
Malvernian hornblendes; their genetic relationship. (Brammall, Leech) 388
Marble, J. P. Possible age of monazite from Mars Hill, N. Car. 456
Marmolite 463
McAdams, R. E. Accessory minerals of Wolf Mt. granite, Llano Co., Texas 128, 207
Mélon, J. with Donnay, J. D. H. Crystallography of ammonium molybdo-ditellurate 250
  ——— Crystallography of caesium molybdo-tellurates 299
  ——— Crystallography of lithium molybdo-tellurate 125
  ——— Essai de détermination des propriétés optiques d'un minéral par la mesure, en lumière parallèle oblique, des retards en différents points d'une lame cristalline. [Book review] 331
Merriam, R. and Laudermilk, J. D. Two diopsides from southern California 715
Merritt, C. A. Castellated dolomites from Major Co., Okla. 604
Merwin, H. E., with Greig, J. W., and Posnjak, E. Separation planes in magnetite 193, 504
Metamorphic differentiation at contacts between serpentinite and siliceous country rock. (Phillips, Hess) 333
Metaxite 463
Meteoric stones from S. Australia—Lake Labyrinth and Kappakoola. (Spencer) 388
Microchemical methods in determinative mineralogy. (Staples) 195, 613
Microscope with universally movable tube. (Sueno) 295
Mine dust, determination of mineral composition by means of *x*-rays. (Walker) 193
Mineral classification according to cleavage and crystal habit. (Seaman) [Book review] 139
Mineral determination by microchemical methods. (Staples) 195, 613
Mineral gallery, how to make the public observe and think. (Walker, Parsons) 196
Mineral museum and the people. (Whitlock) 197
Mineralized spherulitic limestone in the Cheltenham fireclay. (Allen) 369
Mineralogie. (Brauns) [Book review] 815
Mineralogy. (Kraus, Hunt, Ramsdell) [Book review] 676
Mineralogy in the commercial museum. (Toothaker) 196
Mineraloids. (Rogers) 194
Mineralogical Society of America.
  Constitutional amendments and changes in By-Laws 272, 460
  List of former officers and meetings 209
  Nominations for officers for 1937 611
  Preliminary list of titles for 17th annual meeting 817
  Proceedings of 16th annual meeting 183
  Report of auditing committee 271
  Report of committee on nomenclature 188
Mineralogical Society of Great Britain and Ireland 140, 268, 388, 612
Minéraux et les roches, études pratique de cristallographie,

pétrographie et minéralogie. (Buttgenbach) [Book review] 211

Models illustrating arrangement and packing of atoms in crystals, technique for construction of. (Buerger, Butler).... 150

Moehlman, R. S. Amygdaloidal dikes........ 329

Mohler, N. M. Spectrophotometric study of smoky quartz....... 258

Monazite from Mars Hill, N. Carolina, possible age of. (Marble) 456

Montmorillonite, hydrothermal alteration to feldspar at 245°–300°C. (Gruner).....201, 511

Moore Co., N. Carolina, meteorite—A new eucrite. (Henderson, Davis)........ 215

Morey, G. W........ 194

Morse, H. W. and Donnay, J. D. H. Optics and structure of three-dimensional spherulites...201, 391

Morven meteorite, an aerolite from S. Canterbury, New Zealand. (Hutton)........ 268

Mounting minerals for exhibition. (Palache)........ 195

Muench, O. B. Sulfur in cyrtolite and its indication of galena.. 374

Murdoch, J. Adamite from Chloride Cliff, Calif........ 811

——— Andalusite in pegmatite... 68

——— **Silica-fluorite pseudomorphs**........ 18

——— and Webb, R. W. Bustamite from Inyo Co., Calif.... 69

Natural resins, refractive indices of. (Alexander)........ 199

Nepheline contrasts. (Bowen, Ellestad)........ 363

New Haven Mineral Club....... 461

New Mineral names........ ....214, 269, 270, 332, 677

New York Mineralogical Club.... ....140, 141, 390, 536, 612, 816

Nitrogen sulfide, symmetry, unit cell and space group of (Buerger)........ 575

Northrop, S. A. Analysis of thulite........ 73

Nuolate. (Lokka)........ 269

Oborite. (Ho)........ 214

Olivine........198, 701

Opalized spherules, locality for. (Alexander)........ 266

Oriented polished sections of small single crystals. (Buerger, Lukesh)........ 667

Pabst, A. Orientation of minerals in "autoliths."........ 68

——— **Vesuvianite from Georgetown, Calif.**........ 1

Palache, C. Babingtonite and epidote from Westfield, Mass... ....193, 652

——— 195

Paleozoic pegmatites in the Pennsylvania highlands. (Fraser).. 662

Palmquist, S........ 269

Paracoquimbite. (Ungemach)..... 332

Parker, R. L........ 269

Parsons, A. L........ 196

Payne, C. J........ 140

Peacock, M. A. Crystal form of sternbergite........ 103

——— Cyclic permutation of crystallographic axes........ 136

——— Morphological description of diopside crystals........ 318

——— **Roselite and the rule of highest pseudo-symmetry**..202, 589

——— **and Yatsevitch, G. M. Cubanite from Sudbury, Ont.** 55

Peck, A. B. with Slawson, C. B. Determination of refractive indices of minerals by the immersion method........ 523

Philadelphia Mineralogical Society 74, 142, 267, 389, 461, 536, 815

Phillips, A. H. and Hess, H. H. Metamorphic differentiation at contacts between serpentinite and siliceous country rocks 333

——— 194

Phosphatic concretions near Junction City, Ky. (Edmundson) 529

Picrolite........................ 463
Picrosmine...................... 463
Pigeonite, optical data........... 221
Plagioclase feldspars, heat effects on optical orientation of. (Barber)...................... 388
Plagioclase, pyroxene and olivine variation in the Stillwater complex. (Hess)............ 198
Poggendorff, J. C. Biographisch-Literarisches Handwörterbuch für Mathematik, Astronomie, Physik mit Geophysik, Chemie, Kristallographie und verwandte Wissensgebiete. [Book review].................... 535
"Polaroid" for photographing large thin sections in crossed polarized light. (Shaub).......... 384
Porcellophite................... 463
Posnjak, E., and Merwin, H. E. with Greig, J. W. Separation planes in magnetite........193, 504
Potash-feldspars from Goodsprings, Nevada, unusual twin laws. (Drugman)............ 612
Pough, F. H. Bertrandite and epistilbite from Bedford, N.Y... 264
——— 536
Powellite. (Pough).............. 536
"Pseudo-copiapite." (Ungemach). 271
Pseudowollastonite and wollastonite solid solutions with diopside and akermanite. (Schairer, Bowen)................... 193
Psilomelane, pyrolusite and hollandite, *x*-ray studies on. (Vaux).................... 389
Pucherite, *x*-ray study of. (DeJong, DeLange)............ 809
Pyroidesine.................... 463
Pyroxenes...............198, 220, 694
Pyroxmangite, new locality; identity of sobralite and pyroxmangite. (Henderson, Glass) 273

Quartz, method for distinguishing from untwinned oligoclase-andesine. (Dodge)........... 531
Quartz, smoky, spectrophotometric study of. (Mohler).......... 258
Quartz......................... 682

Ramdohr, P.................535, 677
Ramsdell, L. S., Kraus, E. H. and Hunt, W. F. Mineralogy. [Book review].............. 676
Refractive indices of minerals, determination by the immersion method. (Slawson, Peck) 523
Resins, natural, refractive indices of. (Alexander)............ 199
Retinalite...................... 463
Reversible photosensitivity in hackmanite from Bancroft, Ont.: A new property of matter (Lee)...................... 764
Rhodonite, iron rich; analysis, *x*-ray and optical data........ 287
Richardson, C. H., memorial of. (Currier).................. 178
Richmond, W. E. Crystallography of livingstonite...........204, 719
Rogers, A. F..............194, 196, 207
Roselite and the rule of highest pseudo-symmetry. (Peacock) 202, 589
Rosenholtz, J. L. and Smith, D. T. Dielectric constant of mineral powders.................. 115
Ross, C. S. Mineralization of the Virginia titanium deposits..143, 192
Rule of highest pseudo-symmetry. (Peacock)................202, 589
Rutherford, R. L. Optically positive cordierite in Kisseyenew gneiss at Sherridon, Manitoba 386

San Juan region, Colo., petrologic study of the minerals from Tertiary volcanic rocks. (Larsen, Irving, Gonyer, Larsen) 679
Saponite....................... 467
Schairer, J. F.................. 193
Schaller, W. T................192, 202
Scheelite-leuchtenbergite deposit in the Paradise Range, Nev. (Kerr, Callaghan)........... 198

Schmidt, W. and Baier, E. Lehrbuch der Mineralogie. [Book review] 267
Schwartz, G. M. Magnetite metacrysts 635
Schweizerite 463
Seaman, W. A. Mineral classification according to cleavage and crystal habit. [Book review] .. 139
Selfridge, G. C., Jr. *X*-ray and optical investigation of serpentine minerals 463
Seligman, G. Snow structure and ski fields. [Book review] 676
Sepiolite, chemical composition of. (Schaller) 202
Serpentine minerals, *x*-ray and optical investigation of. (Selfridge) 463
Serpentinite 501
Shappell, M. D. Cleavage of ionic minerals 75, 390
Shaub, B. M. Use of "polaroid" for photographing large thin sections in crossed polarized light 384
Shonkin Sag laccolith, differentiation in. (Hurlbut) 198
Silica-fluorite pseudomorphs. (Murdoch) 18
Silica minerals in submicroscopic intergrowths, *x*-ray determination of. (Hurlbut) 727
Silicates, classification of. (Berman) 201
Silicon, simple microchemical test for. (Stables) 379
Simpson, E. S. 140
Slawson, C. B. and Peck, A. B. Determination of refractive indices of minerals by the immersion method 523
——— 195, 197
Smith, D. T. with Rosenholtz, J. L. Dielectric constant of mineral powders 115
Snow structure and ski fields. (Seligman) [Book review] 676
Sobralite, identity with pyroxmangite. (Henderson, Glass) 273
Specific gravity balance, improved. (Kerr) 121
Spencer, L. J. Key to precious stones. [Book review] 611
——— 388, 389, 612
Spinels, gem, from Ceylon. (Anderson, Payne) 140
Staples, L. W. Mineral determination by microchemical methods 195, 613
——— **Simple microchemical test for silicon** 379
——— Book review 139
Sternbergite, crystal form of. (Peacock) 103
Stillwater complex, plagioclase, pyroxene and olivine variation in. (Hess) 198
Stilpnomelane, structure of. (Gruner) 204
Story of gems. (Whitlock) [Book review] 814
Stringham, B. 200
Strunz, H. 269
Sueno, T. Microscope with universally movable tube 295
Sulfur in cyrtolite and its indication of galena. (Muench) 374
Sylvanite. (Tunell, Ksanda) 203
Syromyatnikov, F. V. Mineralogy of asbestos; Ishkyldite, a new structural variety of chrysotile 48

Table for polishing ores, inexpensive. (Hatton) 800
Tabulation of crystal forms and discussion of form names. (Rogers) 207
Taosite. (deLapparent) 678
Tarr, W. A. and Keller, W. D. Dickite in Missouri 109, 195
——— 194
Taylor, W. H. 140
Teaching museum, and aid to class instruction. (Slawson, Denny) 197
Tenham, Queensland, meteoritic shower of 1879 (or 1869?) (Spencer) 612
Thermophyllite 463

Thiesmeyer, L. R. 198

Three-dimensional spherulites, optics and structure of. (Morse, Donnay) 201, 391

Thulite, analysis 73

Tilley, C. E. 268, 612

Titanium deposits, Virginia, mineralization of. (Ross) 143, 192

Toothaker, C. R. 196

Tourmaline, high iron, from Marquette Iron range. (Slawson) 195

Tourmeline inclusions, oriented in muscovite. (Frondel) 777

Trefethen, J. M. Peculiar type of zoning in feldspar 327

Tridymite 687

Trieuite. (De Leenheer) 270

Triplite, analysis 656

Tunell, G. 203

Ungemach, H. 270, 271, 332

Uraninite from Hottah Lake (analysis). (Bruner) 265

Valentinite, crystal structure of. (Buerger) 206

Vanderwilt rock saw, improved. (Emigh) 670

Vaux, G. 389

Vein quartz pseudomorphous after asbestiform actinolite from Blue Ridge of Fauquier Co, Va. (Thiesmeyer) 198

Vesuvianite from Georgetown, Calif. (Pabst) 1, 213

Virginia titanium deposits, mineralization of. (Ross) 143, 192

Vivianite group, crystallography of. (Barth) 204

Vorhauserite 463

Waldo, A. W. 71

Walker, T. L. 193, 196

Watson, E. H. 200

Wayland, R. G. Cummingtonite from Black Hills, S. Dakota . . 607

Webb, R. W. with Murdoch, J. Bustamite from Inyo Co., Calif. . . 69

Wells, A. K. 268

West, C. D. Immersion liquids of high refractive index 194, 245

Whitlock, H. P. Story of gems. [Book review] 197

——— 197

Wilcox, R. Occurrence of large zircon needles in basic pegmatite. . . . 459

Williamsite 463

Winchell, A. N. Third study of chlorite 194, 642

Wolf Mountain granite, accessory minerals of. (McAdams) . . . 128, 207

Wollastonite 193

Woodford, A. O. with Foshag, W. F. Bentonitic magnesian clay-mineral 238

Wright, F. E. 200

Xenoliths in the Organ batholith, N. Mex. (Dunham) 312

***X*-ray powder camera. (Buerger)** . . 11

Yatsevitch, G. M. with Peacock, M. A. Cubanite from Sudbury, Ont. 55

Zincian amphibole from Franklin Furnace, N.J. (Foshag) 63

Zircon needles, large, in basic pegmatite. (Wilcox) 459

Zircon, Siamese, spectrographic examination of. (Kennard, Howell) 721

Zoning in feldspar, peculiar type of. (Trefethen) 327

PRESIDENTIAL ADDRESS

The address of Dr. William S. Bayley, retiring President of the Mineralogical Society of America, will be given Tuesday, December 29, 1936 at 11:40 A.M. in the Hall of Mirrors, before the joint assembly of all societies. Dr. Bayley's address will be on "Mineralogy's Contribution to the Other Sciences and to Industry."

PRESENTATION OF PAPERS

MINERALOGY, PHYSICAL-CHEMICAL MINERALOGY, AND CRYSTALLOGRAPHY

Tuesday Afternoon, December 29th

(1) THE SYSTEM, $NaAlSiO_4$–FeO–SiO_2, by Norman L. Bowen.

In a system with the above components fayalite and albite are binary compounds. The results of a study of mixtures of fayalite and albite have already been published. The join, fayalite-albite, divides the general triangle into two parts in one of which there is a ternary eutectic between fayalite, albite and silica, with a temperature of 980° and containing only some 5 per cent fayalite. In the other portion of the triangle there are certain complications due to the appearance of the oxide phases wustite and hercynite but in the area where these phases do not appear there is a ternary eutectic between nepheline, albite and fayalite with a temperature of 990° and containing only some 10 per cent of fayalite. These mixtures are not unrelated to certain soda-rich rhyolites, trachytes and phonolites and the determinations throw some light on the genesis of such rocks.

(2) OBSERVATIONS ON THE PRODUCTION OF SYNTHETIC GEMS, by Edward H. Kraus.

Observations made at the plants at Locarno, Switzerland, and Bitterfeld, Germany, where synthetic gems are manufactured, will be summarized. Certain phases of the process of manufacture and some of the characteristic properties of synthetic ruby, sapphire, spinel, and emerald will be discussed.

(3) FURTHER STUDIES OF THE ZEOLITES, by A. N. Winchell.

The square diagrams previously used to represent the variations in composition in zeolites have been corrected and modified to include new data. As before, they show that zeolites vary in composition chiefly in the same way as feldspars. They also show that the variation consists essentially in the addition of silica. Accordingly, it is possible to consider these variations in terms of the *three* molecules: $CaAl_2O_4$, $Na_2Al_2O_4$, and Si_2O_4. This makes it possible to represent the composition of all zeolites on ternary diagrams, which are more satisfactory than the square ones previously used. Finally, variations in optical properties corresponding with these variations in composition are not easily defined, because variations due to other causes are commonly present, but a diagram for thomsonite has been prepared.

(4) THE TREND OF MINERALOGICAL RESEARCH, by W. A. Tarr.

The attempt is made in this paper to determine the trend in mineralogical research by an analysis of the leading articles in the *American Mineralogist* and the *Mineralogical Magazine* for the last two decades. The material in the two journals is classified under several heads, such as physical properties, crystal structure and x-rays, chemical mineralogy, origin, and descriptive mineralogy. The analysis reveals an interesting distribution of the subject matter, and evidence of certain fairly definite trends.

(5) UNGEMACHITE AND CLINO-UNGEMACHITE—NEW MINERALS FROM CHILE, by M. A. Peacock and M. C. Bandy.

Ungemachite is rhombohedral—$\bar{3}$; $a:c=1:2.2966$; $\alpha=62°51\frac{1}{2}'$; thirty forms. Habit, thick tabular {0003} {111}. Cleavage {0003} {111} perfect. $a_0=10.84\pm0.02$ Å, $c_0=24.82 \pm0.05$ Å; $a_0:c_0=1:2.290$; V_0 (rhombohedral cell) $=842$ cubic Å. Cell content: $Na_8(K, Fe''')_4 (OH)_2(SO_3)_6 \cdot 10H_2O$, with K:Fe''' about 3:1. $H=2\frac{1}{2}$. $G=2.287\pm0.003$ (Berman). Colourless, transparent; uniaxial, negative; $nO=1.502$, $nE=1.449$. Analysis (Gonyer): Na_2O 21.61, K_2O 11.35, Fe_2O_3 7.69, SO_3 40.23, H_2O 16.69, N_2O_5 trace, insol. 2.07, sum 99.64. Occurs with sideronatrite in massive altered iron sulphates at Chuquicamata, Chile. Named in honour of the late Henri Ungemach of Strasbourg.

Clino-ungemachite is monoclinic; $a:b:c=1.6327:1:1.7308$; $\beta=110°40'$; twenty-four forms; lattice {100} centered. The simple lattice is pseudo-rhombohedral, very like that of ungemachite, with which it is intimately associated. The properties are close to those of ungemachite, but the material is insufficient for a chemical analysis.

(6) PARAGENESIS OF THE URANIUM-BEARING AND ASSOCIATED MINERALS OF THE RUGGLES' PEGMATITE NEAR GRAFTON CENTER, NEW HAMPSHIRE, by Benjamin M. Shaub.

Recent work in mining for feldspar at the Ruggles' pegmatite has exposed numerous uranium-bearing and rare-earth minerals. The uraninite occurs as a three-dimensional dendritic intergrowth in plagioclase feldspar and closely associated with apatite. The alteration of these is attended with a group of hydrous uranium-bearing phosphates. Galena and other sulphides are sparingly present with the original minerals of this group. Beryl is apparently absent, however, in lower openings along the strike down the mountain, but undoubtedly a continuation of the main pegmatite mass, it occurs sparingly. On an older dump pieces of lithiophyllite intimately associated with pyrrhotite, chalcopyrite and other sulphides weighing up to 50 pounds were found. More than 30 mineral species are already known from this mineral deposit. The pegmatite mass is intruded into strongly metamorphosed schists along their strike, but it often cuts sharply across the foliation. Both are cut by later diabase dikes.

(7) THE CRYSTAL STRUCTURE OF KRENNERITE, by George Tunell and C. J. Ksanda.

Well-developed faceted crystals of krennerite from Cripple Creek, Colorado, previously measured by Dr. M. A. Peacock on the two-circle reflection goniometer, were investigated by means of the Weissenberg *X*-ray goniometer. The dimensions of the unit cell were found to be: $a_0=16.51$ Å, $b_0=8.80$ Å, $c_0=4.45$ Å, all ±0.03 Å. The unit cell contains 8 "molecules" of $AuTe_2$. The systematically missing spectra limit the space-groups possible for krennerite to three, namely, $Pmc-C_{2v}^2$, $Pma-C_{2v}^4$, and $Pmma-V_h^5$. From an analysis of the intensities of the diffraction spots on our Weissenberg negatives, from consideration of the close relationship between the structural lattices of krennerite and calaverite as determined by our Weissenberg studies of single crystals, and from the close similarity of the powder photographs of the two minerals both as to positions and intensities of the diffraction lines, the atomic arrangement in krennerite must be one that is isomorphous with the space-group $Pma-C_{2v}^4$. The values of the 18 parameters were determined from the intensities alone. The structure of krennerite is closely related to that of calaverite although the two minerals crystallize in different systems.

(8) A MINERALOGIC STUDY OF SILICOSIS, by R. C. Emmons and R. Wilcox.

The observation has been made repeatedly that certain mineral associations with quartz render dusts harmless from the silicosis viewpoint. An attempt has been made to learn the underlying principles. Experiments have also been carried out to learn what other minerals may cause silicosis.

(9) AN UNUSUAL FELDSPAR FROM THE NORTHERN INYO RANGE, by George H. Anderson and Donald D. MacLellan. (Geological Society Project.)

In studying thin sections of Boundary Peak granite from the Northern Inyo Range Dr. Anderson noted the occurrence in considerable abundance of an untwinned optically positive feldspar of lower birefringence and index than albite. These grains are commonly fringed with myrmekite wherever they are in contact with plagioclase.

Dr. MacLellan undertook a detailed study of the optical properties of the feldspar with the aid of the universal stage. This yielded the following results:

Crystal system, triclinic. Extinction angles: X on best cleavage (probably 001), 7° to 10°; Z on second best cleavage (probably 010), 10° to 15°. Optic angle variable, mostly ranging from 80° to 86° but in a few grains as low as 64° and in one or two as high as 89°. Indices: $N_g = 1.524$, $N_m = 1.520$, $N_p = 1.518$. Birefringence $= .006$.

An x-ray study undertaken by Dr. Linus Pauling and Dr. J. H. Sturdivant confirmed the triclinic character of the mineral and showed that it is distinctly different in several respects from both microcline and orthoclase.

Since the mineral can be distinguished from ordinary feldspars only in thin section, material for analysis could be secured only by digging individual grains from sections slightly thicker than standard. It was practically impossible to secure sufficient amounts for chemical analysis, but a quantitative spectroscopic determination by Dr. Maurice Hassler showed the following composition: K_2O, 11%; Na_2O, 2.7%; CaO, 0.3%; BaO, approximately 0.5%; SrO, approximately 0.01%; MgO, approximately 0.02%, Fe_2O_3, approximately 0.04%.

The mineral is therefore a positive triclinic potassic feldspar different in several respects from any other described species.

(10) THE VALENCES OF IRON IN PYRITE AND MARCASITE, by M. J. Buerger.

A determination of the crystal structure of arsenopyrite has shown that the iron atom has a radius of 1.13 Å, which is smaller than its generally accepted radius, 1.24 Å, while the sulfur atom has a radius of 1.10 Å, which is correspondingly larger than its generally accepted radius, 1.04–1.06 Å. The sulfur and iron radii in arsenopyrite are the same as those found in marcasite and lollingite. They differ from the values found in any other group of crystals including the pyrite group. An extrapolation of the radii of transition metals given in tables by Pauling and Huggins shows that the radius of iron in the marcasite packing is just what would be expected if the iron atom were in the ferric state rather than in the ferrous state as it is in pyrite.

The parameter values for sulfur in marcasite which control the calculated sizes of the atoms in that crystal have been criticized by Pauling and Huggins because the atom radii values do not correspond with the accepted values. The marcasite parameters have therefore been completely redetermined using the unequivocal new Weissenberg methods. All possible planes hKO and h)1 which can be recorded with MoKα radiation have been registered on both underexposed and overexposed Weissenberg equator films for the purposes of comparing strong and weak reflections respectively. A complete study of the variation of these intensities with parameter change has also been carried out. The results completely confirm the earlier study of marcasite, and it can be confidently affirmed that marcasite has a small iron atom and a large sulfur atom.

It therefore appears that the iron in pyrite and marcasite is in different valence states: pyrite is ferrous disulfide while marcasite is ferric disulfide. This gives an entirely new meaning to the Stokes test for pyrite vs. marcasite, and a possible new significance to the differential genesis of these two forms from different chemical environments.

(11) A Rare-Alkali Biotite from Kings Mountain, North Carolina, by Frank L. Hess and Rollin E. Stevens.

The paper concerns the occurrence of biotite containing rare alkali metals, associated with mica schists bordering pegmatites. Dark mica, developed notably in mica schist at the contact with a pegmatite, both at Tin Mountain, South Dakota and Winterham, Virginia, were found to contain small quantities of lithium, caesium, and rubidium. These two occurrences suggested that where dark mica was found developed at the border of a pegmatite, especially one carrying lithium minerals, it should be examined for rare alkali metals.

In the examination of spodumene bearing pegmatites, enclosed in mica schists, from Kings Mountain, North Carolina, brownish mica was found which was supposed to have come from the schist at its contact with the pegmatite. The pegmatite with which the mica is associated is unusual in that dark minerals are exceedingly scarce. Spodumene makes up 15 to 20% of the mass.

The composition of the Kings Mountain biotite as compared to that from Tin Mountain, South Dakota, shows less iron and more silica. The percentages of alkali oxides present are almost identical. The quantity of fluorine present seems to explain why the border biotites carry the alkali metals usually found in the zones of highest temperature. Some fluorides are notably soluble at comparatively low temperatures and it seems probable that the alkali metals were carried as fluorides to the sides of the pegmatites and there entered into the biotites of the enclosing schists.

(12) The Symmetry of Ice, by Austin F. Rogers.

A careful study of ice and snow crystals and their solution forms indicates that ice belongs to the dihexagonal pyramidal class ($A_6 \cdot 6P$) of the hexagonal subsystem. This determination of the symmetry is confirmed by the *x*-ray work of Bernal and Fowler.

(13) Some Notes on the Structure of Stilpnomelane, by John W. Gruner.

Eight analyses of stilpnomelane suggest the formula

$$(OH)_{20}K(Fe\ Mg)_9\ (Fe\ Al)_{5-6}\ Si_{16}\ O_{39-40}$$

Five of the eight were *x*-rayed, three of them not being available. The photographs suggest a layer structure similar to chlorite and mica with the following dimensions $a = 5.4$ Å, $b = 9.3$ Å, $c = 24.1$ Å. This unit cell contains two molecules of the formula above. So far it has been impossible to arrange sheets of the mica, brucite, or kaolinite type in such a way that the intensities of the basal reflections in the photographs can be explained satisfactorily. Many plausible combinations have been tried. Also heating of the mineral up to 740°C. has offered no clue. It is stable at temperatures at least as high as 500°C., but at 600°C. the structure is partly destroyed. A shrinkage from 24.1 Å to about 22 Å in the direction normal to the cleavage occurs at this temperature.

(14) Cristobalite at Crater Lake, Oregon, Carl E. Dutton.

Although cristobalite is not uncommon in the andesites of the Cascade Mountains, the occurrence at Crater Lake is somewhat unusual because of the well developed complete and skeletal octahedrons.

(15) The Crystallographic Series of Baumhauer and Ungemach, a Theoretical Consequence and Factual Confirmation of the Law of Bravais, by J. D. H. Donnay.

Ungemach, after Baumhauer, showed that, if the axial elements are correctly chosen, the main faces of a crystalline species are distributed in "series" covering the principal half-tones. E.g.: series (011), (021), (031), (041), . . . covers the segment of zone [100] that extends from (011) to (010); series (011), (012), (013), (014), . . . covers the segment (011)–(001) of the same zone. Such "simple primary" series are obtained by adding the indices of the "pole," i.e. (001) in the latter case and (010) in the former, to the indices of the starting face, i.e. (011) in both examples. The series may be of different types, according to Ungemach's observations. Example of a double primary series: 011·031·051·. . ., with (020) as its pole. Example of a simple secondary series: 032·052·072·092·. . .; forms of the secondary series are obtained by addition of indices of two consecutive faces in a primary series. Secondary forms have been observed among the first members of otherwise normal primary series. The type of series found depends on the mode of centering of the (morphological) lattice.

Such empirical observations are shown to be direct consequences of the Law of Bravais. It is possible to predict what types of series are to be expected in the various half-zones, for different lattice modes. This affords easy criteria for the determination of the (morphological) lattice and "correct" axial elements.

(16) CHECKING INDEX LIQUIDS WITH THE MICROSCOPE, by C. B. Slawson.

The index of refraction of a liquid is measured with a microscope so constructed that the tube can be inclined to the side through an arc of 10°. The range of the index of refraction determinations extends from 1.330 to 1.880. A slit diaphragm placed in the condenser converts it into a collimating system and the microscope with the Bertrand lens inserted and an objective of proper focal length becomes a telescope. It then functions as a goniometer. A microscope slide with an accurately beveled edge placed upon a second slide forms the hollow glass prism which holds a few drops of the liquid.

(17) ON NORMAL TRICLINIC FACE-SYMBOLS AND THE HARMONIC-ARITHMETIC RULE, by M. A. Peacock.

If the Law of Bravais were strictly true, as applied to the simple structural lattice, the gnomonic projection points of the faces in a zone-quadrant would form the simultaneous series:

$$\begin{array}{ccccccccc}
0\cdots\frac{1}{3} & & \frac{1}{2} & & & 1 & & 2 & 3\cdots\infty \\
0 & \cdots & (\frac{2}{4}) & \frac{2}{3} & & (\frac{2}{2}) & \frac{3}{2} & (\frac{4}{2})\cdots & \infty \\
0 & & \cdots & \frac{3}{5} & \frac{3}{4} & (\frac{3}{3}) & \frac{4}{3} & \frac{5}{3}\cdots & \infty \\
 & & & & & \cdots & & &
\end{array}$$

in which the end terms represent the planes with the greatest and second greatest spacings while the unit term represents the plane with the third greatest spacing in the quadrant. These *normal series*, corresponding to *normal face-symbols*, are harmonic from unity to zero, arithmetic from unity to infinity. The Law of Bravais predicts the relative extent of the several series in any one zone, and the degree to which either the harmonic or the arithmetic part may preponderate.

Analysis of a sufficient number of highly developed triclinic zones reveals a fair approach to the ideal series. In spite of irregularities, which constitute exceptions to the Law of Bravais, the proposed *Harmonic-Arithmetic Rule* leads unambiguously to the structural lattice, when applied to the gnomonic projection of the forms of a triclinic crystal on the plane normal to the axis of the main zone.

(18) THE WEISSENBERG TREATMENT OF CRYSTALS BELONGING TO THE OBLIQUE SYSTEMS, by M. J. Buerger.

The angles between planes in a crystal may be determined in a number of ways by the Weissenberg method. These include (1) the direct determination of the angle on the Weissenberg film, between the Z lines containing the orders of reflection of the two planes on the equatorial photograph, and (2) the determination of the offsets of dome reflections on n-layer films as compared with the lines of corresponding pinacoid reflections on the equatorial film. Neither of these methods is accurate unless the Weissenberg translation motion is impracticably long. A method of extreme precision is the following: In a monoclinic crystal, the reciprocal lattice vectors, a*, c*, c*–a*, form a triangle, one of whose angles is the crystallographic element β. Measurements of the Bragg angles of reflection from the planes (100), (001), and ($\bar{1}01$) will therefore yield data which will permit a calculation of β with the same precision as the other cell constants. A similar method may be used to calculate any interfacial angle. In triclinic crystals, this calculation does not yield the angles α, β, and γ directly, but rather the polar angles λ, μ, and ν, from which α, β, and γ may be calculated by the familiar Goldschmidt polar form relation. The development of a new instrument (mentioned in another abstract) for the extremely accurate determination of lattice spacings, now makes it possible to determine not only the cell edges, but also their angles of inclination and, of course, the axial ratio, with an accuracy exceeding that of optical goniometer methods. The new x-ray methods have the additional advantage that they can be applied to crystals with incomplete form development and crystals whose perfection is too low to permit ordinary optical goniometer work with any accuracy.

(19) ENANTIOMORPHOUS QUARTZ IN TECTONITES, by H. W. Fairbairn.

A statistical analysis was made of the orientation of quartz from a Cambrian quartzite in southern Quebec. Approximately 10,000 grains were measured from 19 thin sections, collected over a strikewise distance of 14 miles. The most prominent maxima in the orientation diagrams (loci of greatest orientation of quartz axes) correspond to Maximum IV of Sander (see D. 61 in Gefügekunde der Gesteine), and all four are symmetrically placed with respect to the projection line of the quartzite foliation surfaces. This maximum has not yet been satisfactorily explained and the following interpretation is offered. Gliding occurred parallel to rhombohedral planes of the quartz. The glide directions in these planes are not, as is usual, in a plane containing the vertical crystallographic axis, but are oblique, with a statistical arrangement which corresponds to the trapezohedral symmetry of enantiomorphous quartz. Two of the maxima in the diagrams originate from right-handed grains; two from left-handed. Since the structure of low-quartz is still uncertain it is not yet possible to correlate these assumed glide directions with known directions of greatest atomic density.

(20) THE STAUROLITE BELTS OF PATRICK AND HENRY COUNTIES, VIRGINIA,* by Charles H. Moore, Jr.

The staurolites in these two counties occur in two roughly parallel belts. One belt begins at a point four miles southwest of Stuart and extends in an approximate N 50 E direction for a distance of about nineteen miles. The other begins at a point nine miles northeast of Stuart and one-half mile southeast of the first belt and extends to and beyond the Franklin County line. The belts are roughly lenticular in shape and have a maximum width of two and one-half miles.

The three principal rocks associated with the staurolites are a biotite chlorite schist, a sericite staurolite schist, and an iron-stained quartz mica schist. These rocks form a portion of the Wissahickon formation where the Martic overthrust block overrides the Lynchburg gneiss. They form a sharp contact with the Lynchburg gneiss along their western boundary and grade into less metamorphosed Wissahickon on the east.

The staurolites occur as reddish brown idioblastic crystals one-tenth inch to one and one-half inches in length in each of the three rock types, and are altered wholly or in part to sericite or chlorite. They contain numerous inclusions of small garnets which weather out, giving the appearance of pits in the staurolite crystals. The staurolites appear to be most numerous near the ends of the lenticular belts.

---

* By permission of the Virginia Geological Survey.

(21) HELIUM RATIO OF FLORIDA ANHYDRITE, by William D. Urry. (Geological Society Project.)

The rate of production of helium from the radioactive elements uranium and thorium being constant, a determination of these elements and the helium in rocks and minerals affords a measure of their age. Determinations have so far been confined to igneous rocks with the exception of the Anhydrite here reported. The Anhydrite drill core was taken from the South Lake Well, Florida, from a deposit 180 feet thick, at a depth of 2560 feet, the well starting in the Ocala limestone. Stratigraphic evidence places it most probably in the earliest Eocene and the computed age 71 ± 6 million years—late Cretaceous to early Eocene compared with the time scale from the igneous rocks—is in good accord with the stratigraphic evidence. If such agreement is borne out in further work the application of the method to the field of minerals will greatly aid in the solution of chronological problems of mineralization.

MINERALOGY, PETROGRAPHY, AND PHYSICAL-CHEMICAL MINERALOGY

Wednesday, December 30th

(22) THE DISTRIBUTION OF LITHIUM IN ROCKS AND MINERALS AS REVEALED BY QUANTITATIVE SPECTRUM ANALYSIS, by Lester W. Strock.

The material to be presented is the result of a study of the Geochemistry of Lithium made in the Laboratory of Prof. V. M. Goldschmidt at Göttingen University. A specially accurate quantitative method of optical spectrum analysis was devised capable of determining Lithium to an accuracy of ±3% in the range 0.0001 to 3.5% Li_2O. The method will be briefly outlined. The amount of Li_2O in all the various types of primary, sedimentary, and some metamorphic rocks was determined. After determining the Li_2O content of sea water, the geochemical balance was calculated by the method of Prof. V. M. Goldschmidt. The most interesting results were obtained by analysing the individual mineral components of rocks separately, which furnish one of the most excellent examples known for the important manner in which the laws of crystal chemistry may be applied in explaining isomorphism in minerals. The entire study illustrates the excellent service which quantitative spectrum analysis can render to mineralogy.

(23) UNUSUALLY HIGH FELDSPAR CONTENT OF THE GLENWOOD FORMATION, by John W. Gruner.

The Glenwood formation is of Ordovician age. Near Minneapolis it consists of a number of beds of clayey material which contain well rounded quartz grains all of which appear to be larger than 1/10 mm. The material smaller than this size was analyzed chemically and by *x*-rays. This fine material of one of the beds consists chiefly of potash feldspar. As a matter of fact, enough potash is present for two-thirds of the material to be feldspar. *X*-rays give the feldspar pattern only, even for sizes as small as one micron. Below this dimension many of the diffraction lines become very broad. While the feldspar pattern still persists, diffusion bands common to amorphous substances appear. The extremely small size of the feldspar particles raises the question as to the genesis of them. It is not thought likely that they represent simply a disintegration product of large crystals. The feldspar is probably secondary like authigenic material though no nuclei were necessary for its formation.

(24) The Plantersville Meteorite, Grimes County, Texas, by John T. Lonsdale.

The Plantersville meteorite fell on the afternoon of September 4, 1930 at a point 3½ miles southwest of Plantersville, Grimes County, Texas. The locality of the fall is forested but several men were working nearby and recovered the specimen within a few minutes of its fall. The phenomena of fall included rumbling explosions and a noise like an airplane in flight. This find is a light gray friable aerolite, weighing 2084.9 grams, with a dense black crust showing oriented thread lines. The shape is sub-conoid faceted with a well developed brustseit. The dimensions are $5\frac{3}{4}'' \times 4'' \times 3\frac{3}{4}''$, measured in three directions at right angles.

The texture of the meteorite is largely crystalline but glass is present in chondrules and also as an interstitial material in the groundmass. A relatively small number of minute veins of metal occur. Many chondrules are present most of which are angular or fragmental. The minerals present include hypersthene, chrysolite, a monoclinic pyroxene, metallic iron, troilite, black and colorless glass, and a reddish-brown spinel. Chemical and spectographic analyses are included in the paper.

(25) Origin of the Canadian Apatite-Phlogopite Deposits, by Kenneth K. Landes.

Apatite-phlogopite deposits lying in the watersheds of the lower Catineau and Lievre rivers in southwestern Quebec and one deposit near Wilberforce in southeastern Ontario were examined. The pre-Cambrian metamorphic complex has been intruded by bodies of pyroxenite. The field relationships do not justify the conclusion heretofore held by some geologists that the pyroxenite is metamorphosed limestone. The pyroxenite intrusion was followed by the injection of coarse mauve-colored microcline accompanied by quartz in varying amounts. This feldspathic magma was perhaps a differentiate of the pyroxenite magma. A still later after effect of the pyroxenite intrusion was the deposition by hydrothermal solutions of actinolite, scapolite, phlogopite, coarse apatite, and "sugar" apatite with calcite, in the order named. The pyroxenite bodies and the country rock are alike cut by much later dikes of white microcline-quartz pegmatite.

(26) Crystallography of Synthetic Burkeite, by Lewis S. Ramsdell.

Crystals of synthetic burkeite, $2Na_2SO_4 \cdot Na_2CO_3$, have been obtained by evaporation from solution at 70–80°C. The crystals are usually twinned, but single individuals occur occasionally. Goniometric measurements give an axial ratio of 0.534:1:0.750. The usual forms present are (110) and (111). The twins consist of trillings, with (110) as the twinning plane.

(27) The Ternary System, Leucite-Diopside-Silica, by J. F. Schairer.

The field of diopside occupies a large portion of the phase diagram of the ternary system and diopside is the primary phase in some compositions with less than two per cent by weight of that compound. The ternary eutectic (solid phases—diopside, tridymite, orthoclase) and the ternary reaction point (solid phases—leucite, orthoclase and diopside) lie at compositions very close to the binary eutectic and binary reaction point in the system, leucite-silica. The field of orthoclase is very small. Residual liquids in fractional crystallization are rich in alkali-alumina silicates.

(28) Lamprophyres of the Bay of Exploits, Newfoundland, by George R. Heyl.

A group of lamprophyre dikes, chiefly monchiquites and fourchites, occur in the Bay of Exploits area of northeastern Newfoundland. Their spatial distribution indicates that they are genetically connected with the granodiorite batholiths of the region. They are the youngest intrusive rocks in the area and represent the final stage of the batholith differentiation.

The large phenocrysts of biotite and hornblende present in these dikes show pronounced evidences of resorption and reaction, indicating that they were unstable in the magma at the time of its intrusion. One of these dikes contains a great number and variety of inclusions which likewise show marked reaction and resorption effects. The reactions are of a type which would occur with an abrupt drop in pressure. Many of these dikes show fine-grained or aphanitic selvages which are interpreted as the chilled facies.

The evidence indicates that the lamprophyres were intruded as a magma which in most cases contained some intratelluric crystals in suspension. The changes in thermodynamic conditions during the transfer and injection of the magma resulted in these crystals becoming unstable. The minerals that were stable at the time of freezing of the dikes were those which have crystallized in the groundmass. A relatively low temperature of freezing of these rocks is suggested by the abundance of primary analcite in them; this is corroborated by the lack of thermal metamorphism in the rocks immediately adjacent to the dike walls.

The lamprophyre magma is conceived to have formed by the interaction of the residual magma of a batholith with the more basic deep-lying portions of the batholith. A magma unusually rich in femic molecules and hyperfusibles would result. Of the hyperfusibles water was by far the most abundant; in addition there was a concentration of carbon dioxide, fluorine, chlorine, phosphorus and sulphur. Because of the concentration of hyperfusibles, the vapor tension would be high, and if it exceeded a certain limit the magma would be injected outward and upward into the surrounding rock. This would be accompanied by rapid transfer of material and an abrupt drop in pressure, and, upon freezing, lamprophyre dikes would result. Such a history is indicated by the lamprophyres of the Bay of Exploits.

(29) Origin of the Marcasite Sink-hole Deposits of Central Missouri, by W. A. Tarr.

There are ten known deposits of marcasite (and pyrite in small quantities) in sink-holes in Franklin, Crawford, and Phelps counties in the northeastern part of the Missouri Ozarks, and others probably exist. Only two are active producers, at present. These sulfide deposits occur in the lower part of the sink-holes, the upper part having been occupied by hematite which has been removed by mining. The sulfide reaches a maximum thickness of 30 feet in some deposits and may be approximately 200 feet wide. The overlying hematite was pseudomorphous after the sulfides. The marcasite is accompanied by masses of sandstone and quartz as the chief gangue minerals. The contact of the ore with the walls of the sink-hole is normally sharp, locally it is gradational. The marcasite is massive, mammillary, stalactitic, botryoidal, granular, crystalline, and porous.

It is believed that the deposits were formed by hydrothermal solutions which rose from a hidden igneous mass below and deposited sulfides in the sink-holes under a cover of Pennsylvanian shales. The hematite resulted from the oxidation of the upper portion of the sulfide mass.

(30) Origin of the Chert in the Tri-State (Missouri-Oklahoma-Kansas) Zinc-Lead District, by Chalmer J. Roy.

Three types of siliceous rocks are found in association with the sulphide ores of the Tri-State district, namely, early chert, late chert and jasperoid. The early chert, occurring as nodules and nodular beds, is found in the Mississippian limestones throughout the Mississippi valley and is believed to have formed as a penecontemporaneous replacement of the limestone. The late chert, occurring as massive beds, veins and silicified fault zones in the mining area only, is definitely epigenetic. The jasperoid occurs in intimate association with the sulphides and is believed to be contemporaneous with them, but later than the late chert. The late chert and jasperoid are believed to represent two phases of the ore mineralization, one (the late chert) early and barren of sulphides, the other later and containing abundant sulphides. Both are believed to be hydrothermal.

(31) THE MINERALOGY OF THE WISCONSIN LEAD-ZINC ORES, by Charles H. Behre, Jr.

Recent mineralographic studies of the Wisconsin lead-zinc ores have revealed relationships bearing on their origin. The recognized sequence, as in similar European districts, was iron sulphide (loosely designated "marcasite"), sphalerite, galena, late barite, accompanied by long-extended calcite and iron sulphide deposition. Banfield and Born showed that much of the "marcasite" was actually pyrite; both minerals are colloform and their relations and similarity in form suggest paramorphism of pyrite after marcasite. An almost constant feature is a thin film of pyrite between country rock and ore.

The zinc sulphide is also largely colloform and in long bladed crystals, thus resembling the Silesian "Schalenblende" (wurtzite). Its presence favors acid waters as depositing agents. Some arsenic is present but in what mineral is not known.

Barite is conspicuously late as compared with the sulphides, thus differing from that in peripheral deposits of typical meso- and epithermal ores. Some silicification is chert-like but whether primary or secondary is till uncertain. Calcite in scalenohedral forms cements shattered sphalerite or wurtzite and typifies the late form of the carbonate, as compared with the earlier, rhombohedral form.

The replacement ores are quantitatively negligible, fissure fillings preponderating. Structural relations of the ores are not here discussed in detail, but the resemblance to the Silesian zinc ores, both structurally and mineralogically, is striking.

(32) CLASSIFICATION OF THE NATURAL SILICATES, by Charles K. Swartz.

It is the author's purpose to bring together the results of x-ray analyses, thus far published, bearing upon the problem of the mutual relations and chemical composition of the natural silicates and to present a classification of the silicates based upon the data thus assembled.

The principles underlying the classification will first be briefly discussed. It will be shown that there are five fundamental types of natural silicates whose character and composition will be illustrated. It will be shown further that these fundamental types may combine among themselves to produce more complex assemblages, a number of which have thus far been observed.

The relations of the classification here proposed to those of Bragg, St. v. Naray-Szabo and Machatschki will be considered briefly.

A table will be given showing the classification of the chief families of silicate minerals. A detailed table has been prepared and will be published later, giving the composition of the natural silicates whose structure has been determined by x-ray analyses up to the present time, together with literature citations.

(33) THE STRUCTURAL LATTICE AND CLASSIFICATION OF BUSTAMITE, by Harry Berman and Forest A. Gonyer.

Bustamite ($CaMnSi_2O_6$) was formerly regarded as a lime rhodonite; more recently it has been considered as a manganese wollastonite. Since bustamite does not occur in faceted crystals it was not possible to help settle the question by morphological comparisons. X-ray measurements on a cleavage fragment yielded the following triclinic lattice dimensions: $a_0=7.64$ Å, $b_0=7.16$ Å, $c_0=6.87$ Å; $\alpha=92°08'$, $\beta=94°54\frac{1}{2}'$, $\gamma=101°35'$; $a_0:b_0:c_0=1.067:1:0.959$. The values are close to those of wollastonite. An analysis of the studied material leads to the cell content: $Ca_3Mn_3Si_6O_{18}$, which compares with the cell content of wollastonite: $Ca_6Si_6O_{18}$. The present study thus shows that bustamite is a manganese wollastonite, confirming the conclusion previously reached from optical study and powder photographs.

(34) VEIN-FILLING AT NEVADA CITY, CALIFORNIA, by W. D. Johnston, Jr.

A grant from the Penrose Bequest made possible the continuation in 1934 of work begun at Nevada City in 1931.

The principal ore minerals in the gold-quartz veins of Nevada City are pyrite, arsenopyrite, sphalerite, chalcopyrite, galena, and tetrahedrite, with lesser amounts of molybdenite and gold. They were deposited in the earlier stages of vein-filling in a quartz gangue. In the later stages of vein-filling carbonates were the dominant gangue minerals. Galena, tetrahedrite, and gold were introduced late in the quartz sub-stage.

Unique in a district where most mines produce by weight more gold than silver is the Central Mine of the Lava Cap Gold Mining Corporation where the ratio of gold to silver by weight is 1 to 12+ due to unusual abundance of argentiferous tetrahedrite. Pyrargyrite is found rarely in the Central Mine.

Quartz textures give some clue to vein history. Combs and massive homogeneous quartz indicate vein-filling without movement of the vein walls; breccias indicate movement with appreciable dilation of the interwall space; and shear structures, such as granulation zones in ribbon quartz and mortar structure, indicate movement without appreciable dilation of the walls.

Most veins show evidence of recurrent deposition of quartz alternating with movement of the walls. Thick veins have been built by alternation of quartz deposition and movement in which the hanging wall was at all times adequately supported.

By permission of the Director, U. S. Geological Survey, Washington, D. C.

(35) HORNFELS-GRANODIORITE TRANSITIONAL FACIES AT CORNUCOPIA, OREGON, by G. E. Goodspeed.

Metamorphic and granodioritic rocks of pre-Tertiary age, form the core of the rugged Wallowa mountains of northeastern Oregon. Near the mining town of Cornucopia, hornfels-granodioritic contacts are common and well exposed. In addition to excellent surface exposures these contacts have been intersected by several long adit tunnels at different elevations.

Transitional facies are found in irregular zones, dike-like and stock-like masses, breccias, and unusual occurrences of angular blocks of granodioritic rock surrounded by hornfels. Some of the transitional facies show first a gradual change from a porphyroblastic hornfels to a rock which would be classified as a porphyry. This grades into a gneissic granodiorite and finally to what would be called a normal granodiorite. In zones which have been affected by cataclastic metamorphism there may be relatively sharp hornfels-granodioritic contacts which may be explained by the selective recrystallization replacement of the crushed material.

It is believed that sufficient field and petrographic evidence has been accumulated to warrant the interpretation that these smaller granodioritic masses have been formed by recrystallization replacement incident to a process of additive dynamothermal metamorphism and that this interpretation may be extended to the larger granodioritic masses.

(36) THE UNIT CELL AND SPACE GROUP OF STERNBERGITE, $AgFe_2S_3$, by Newton W. Buerger.

Sternbergite from Joachimsthal, Bohemia, has been studied by the equi-inclination Weissenberg method. Due to the very plastic nature of sternbergite crystals this study has been very difficult and the cell constants given below are probably rough values. The flexible nature of the crystals has also rendered the *x*-ray reflections poor, and certain other revisions may have to be made.

The investigation leads to the following cell data:

Diffraction symbol: mmmC-c-
Crystal class: C_{2v} or D_{2h}
Crystal system: Orthorhombic
Space group: Cmc or Cmcm
Unit cell:

	Absolute	ratio	Peacock's ratio
$a=$	11.7	1.74	.5913 (×3=1.7739)
$b=$	6.7	1.	1.
$c=$	12.67	1.88_6	.6250 (×3=1.8750)
$Z=$	8 $AgFe_2S_3$ per cell.		

It is evident that the axial ratio derived by surface morphological study should be altered so that *b* has $\frac{1}{3}$ the length assigned to it by Peacock. This change also brings with it the necessity of interchanging the usual *a* and *b* axes in order to leave *b* the longer of the two.

The structural study of this crystal is being continued.

(37) 2E GONIOMETER, by Terence T. Quirke.

A goniometer is made in half-cylinder form, calibrated from 0° at the zenith to 90° at the base. It is used on the stage of an ordinary petrographic microscope using convergent polarized light for the sub-stage illumination. It is convenient to withdraw the barrel of the microscope so that the stage is clear of any obstruction to the placing of the goniometer. The mineral section to be measured must be cut at or near a plane normal to the acute bisectrix. The section is then placed in the 45° position so that the principal optic plane lies at 45° to the plane ot vibration of transmitted light.

In the bottom of the goniometer there is a sheet of polaroid oriented at right angles to the vibration direction of the sub-stage polarized light. The polaroid is oriented in the position of the usual analyser in the microscope but is placed immediately on top of the mineral section between the mineral section and the scale of the goniometer.

When this set up is placed in a dark room and strong light passed through the mineral section from the sub-stage polarizer the eyes of the two optic axes are projected onto the translucent scale of the goniometer where the angle 2E can be read directly.

(38) A UNIVERSAL STAGE METHOD OF DETERMINING BIREFRINGENCE, by R. C. Emmons.

With the purpose in mind of using birefringence as a determinative criterion of minerals when the identity is uncertain after other tests, a method has been developed for learning the birefringence in crystals unfavorably oriented for standard methods of measurement or in crystals of birefringence too high for standard accessories.

(39) SIMPLIFIED GRAPHIC METHOD OF DETERMINING APPROXIMATE AXIAL ANGLE FROM REFRACTIVE INDICES OF BIAXIAL MINERALS, by Harold T. U. Smith.

An adaptation of Wright's graphic plat for solution of the approximate equation makes possible the rapid determination of axial angle and optic sign directly from refractive indices. The necessity for first computing partial birefringences is eliminated. This method provides a convenient check on the consistency of laboratory determinations by the immersion method. Pedagogically, it serves to emphasize the mathematical interrelation between indices, axial angle, and optic sign.

(40) A SYSTEM OF GRIDS FOR THE DETERMINATION OF NON-OPAQUE MINERALS, by J. D. H. Donnay and J. Mélon.

Existent determinative tables require that an unknown mineral be tested, at the outset of the procedure, for certain selected properties in a given order, e.g. optical anisotropy, optical character and sign, refractive index (Larsen-berman); hardness, specific gravity (Rosenholtz-Smith); luster, fusibility (Brush-Penfield). Other properties serve only as a confirmation.

A new device (system of about 200 grids) extends the usefulness of existing tables: (1) It removes the necessity of adhering to any rigid order. (2) Any property may be used directly toward determination, which, therefore, rests mainly on the most striking properties. (3) All minerals in which any given set of properties co-exists are at once sorted out. (4) Even incomplete data regarding certain properties are usable. (5) At any point during the procedure one is guided in his choice of further tests. (6) The fact that a mineral is not included in the grids is automatically detected.

The device is applied to all non-opaque minerals (more than 1200). Its principle of construction has been described elsewhere.* Its chief advantage lies in the mechanical aid it affords in determining minerals.

(41) AN APPARATUS FOR THE PRECISION DETERMINATION OF SINGLE LATTICE CONSTANTS, by M. J. Buerger.

None of the methods developed for the precise determination of lattice constants by powder methods is applicable to crystals more complicated than isometric or hexagonal because the diffraction loci of non-equivalent planes are, in general, unresolved. For the more complicated crystals the diffracted radiation must be obtained from a single crystal and recorded by one of the moving film methods. The Weissenberg arrangement is ideally suited to this purpose because it may include the entire range of reflections and because it provides for focussed spots over the entire range. The Sauter method lacks these advantages.

The instrument constructed for this purpose is one of the back reflection, absolute variety which takes advantage of the strategy: film shrinkage and other corrections $\rightarrow 0$ as $\theta \rightarrow 90°$. To do this, the x-ray beam must be introduced through the center of the Weissenberg film. To avoid film warping, the beam enters a small slot, and the translation motion of the film is reduced to 45 mm. A great deal of unused film is thus retained for strength, for a slot of only 13/8 inches is used in a 5×7 inch film. The camera proper has a radius of 57.26 mm. and the film is wrapped directly about the metal of the camera and unsupported only in the region of the one inch exposed section. The camera design is unique and avoids any accidental exposure of the film to light. The other features of the instrument design follow the standard equi-inclination Weissenberg apparatus, but simplified for this particular application, and made as rugged as possible. With the use of polychromatic radiation from duplex and triplex metal targets, extremely accurate lattice constants are determinable. A chart is presented for the purpose of identifying reflections on this type of instrument.

(42) ON THE TIME REQUIRED TO FORM THE OLIVINE ZONE IN THE PALISADES SILL, NEW JERSEY, by John W. Butler, Jr.

Certain statistical petrologic studies offer quantitative information concerning differentiation and the consolidation history of igneous rocks. An application along this line reveals factors requiring consideration in computing the time necessary for gravitative differentiation to develop the conspicuous olivine zone near the base of the Palisades Diabase Sill, New Jersey.

---

* J. D. H. Donnay: Système de grilles pour la détermination des mineraux. Annales de la Société géologique de Belgique, *59*, B 250–257, 1936.

Several thousand olivine grains were measured in a suite of thin-sections through the olivine zone. Most crystals have diameters of 0.1 mm. or less, few exceed 0.25 mm., and diameters greater than 0.5 mm. are rare in numerical comparisons. Many olivine crystals of all sizes are euhedral. Kind, occurrence, paragenesis, and size of associated minerals are significant also and are recorded.

The importance of detailed statistical observations is illustrated by size of olivine alone. A calculation of the time necessary to form the olivine zone, offered by Bowen, following Stoke's formula assumes olivine grains 0.7 mm. in diameter settled 200–300 meters through magma having viscosity of either 4.0, or, like some basic Hawaiian lavas, 0.5. The respective results were 200–300, and 25–40 hours. Recalculation, after substituting the diameter 0.25 mm. for 0.7 mm., gives values of about 1495–2242 hours, and about 190–285 hours respectively; substituting diameter of 0.1 mm. increases these last values about six times. Mean factors may be derived from petrologic observations throughout the sill.

Statistical tables emphasize the longer time necessary for this phase of gravitative differentiation which, however, was not completed. Subsequent intrusions into the olivine zone of diabase containing less olivine, and occasional deuteric, and hydrothermal effects may be traced through stages of their development.

Thursday, December 31st

(43) REFRACTIVE INDICES OF VITRAINS, by Terence T. Quirke and Louis C. McCabe.

The physical qualities of vitrain appear to vary according to the rank of the common banded coals which contain it. Variations in quality of vitrain are indicated by corresponding changes in the refractive index. The refractive indices of various vitrains range from about 1.60 to above 1.80.

Indices of refraction were computed from the angle of maximum polarization reflected from polished surfaces of vitrain. This has the advantage of avoiding the use of oils of high index of refraction, which are not only difficult to handle in many cases, but awkward to calibrate because their index lies beyond the range of the usual Abbe refractometer.

Determinations were made by means of a reflecting goniometer equipped with an analyzing nicol prism. Measurements were made not only from coal, but also from a series of minerals both transparent and nearly opaque, the indices of which have been determined by other methods.

DATE DUE

GAYLORD

PRINTED IN U.S.A.